NASA CR-132510

FINAL TECHNICAL REPORT

AAFE MAN-MADE NOISE EXPERIMENT PROJECT

VOLUME II
PROJECT AND EXPERIMENT
DISCUSSIONS

JUNE 1974

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Prepared under

Contract NAS 1-11465

Prepared for

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365



National Scientific Laboratories, Inc.
Westgate Research Park, McLean, Virginia 22101

A Subsidiary of Systematics General Corporation

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## 3. PROJECT BACKGROUND AND RATIONALE

In the design and development of future earth/space communication systems, the prevention of communications degradation as a result of radio frequency interference (RFI) will be an important consideration. Interference to the earth satellite receiver may be produced by intra-satellite or intra-space-system devices or by electromagnetic radiation arriving at the antenna from any source other than the intended earth transmitter. Such external interference can consist of intentionally generated (man-made), usually coherent, electromagnetic radiation from surface and near-earth transmitters, and of radiation resulting from atmospheric and stellar activity.

The existence of intra-system interference can be taken into account by attention to the well-known and codified principles and practices of electromagnetic compatibility (EMC) throughout the design and fabrication of the space system.

The potential for interference resulting from reception at the satellite of either intentional or spurious radiation from earth- or aircraft-based radio transmitters is significant and has, in fact, been noted in operational satellite systems. For example, the OSO satellites were subject to interference which was studied and documented.* The available information regarding such interference is sparse and cannot be developed with the necessary scope and accuracy from surface measurements. It was

*"Command Channel RFI and Its Effect on OSD-IV", GSFC X-516-68-413.

toward the development of a feasible experiment to identify, measure and record such interference that this project was directed. Throughout this report, therefore, the terms "RFI", "noise", and "man-made noise" are used to indicate the electromagnetic radiation produced by radio transmitters which could produce degradation in satellite communications links, to the exclusion of other interference forms.

The need for information on the man-made noise environment at orbit altitudes results primarily from the fact that a great portion of the RF spectrum available for earth/space communications is shared with terrestrial services. Figure 3-1 graphically illustrates the magnitude of space- and terrestrial-service sharing through the frequency range 100 MHz to 15 GHz. The sharing of bands by different terrestrial services, like the collocation of carriers on the same frequency in a given service, could be accomplished on a "no-interference" basis until the advent of space communications systems; spatial separation of links provided adequate isolation as a result of line-of-sight propagation through most of the spectrum. However, the field-of-view typical antenna coverage of earth satellites eliminates the isolation previously attainable through physical (line-of-sight) separation of links.

Satellite system receivers may be sensitivity-limited by man-made noise; accurate knowledge of this noise, in the satellite environment, is needed for frequency management, channel selection, signal processing design, and hardware design in support of satellite communications systems. Critical choices relating to encoding

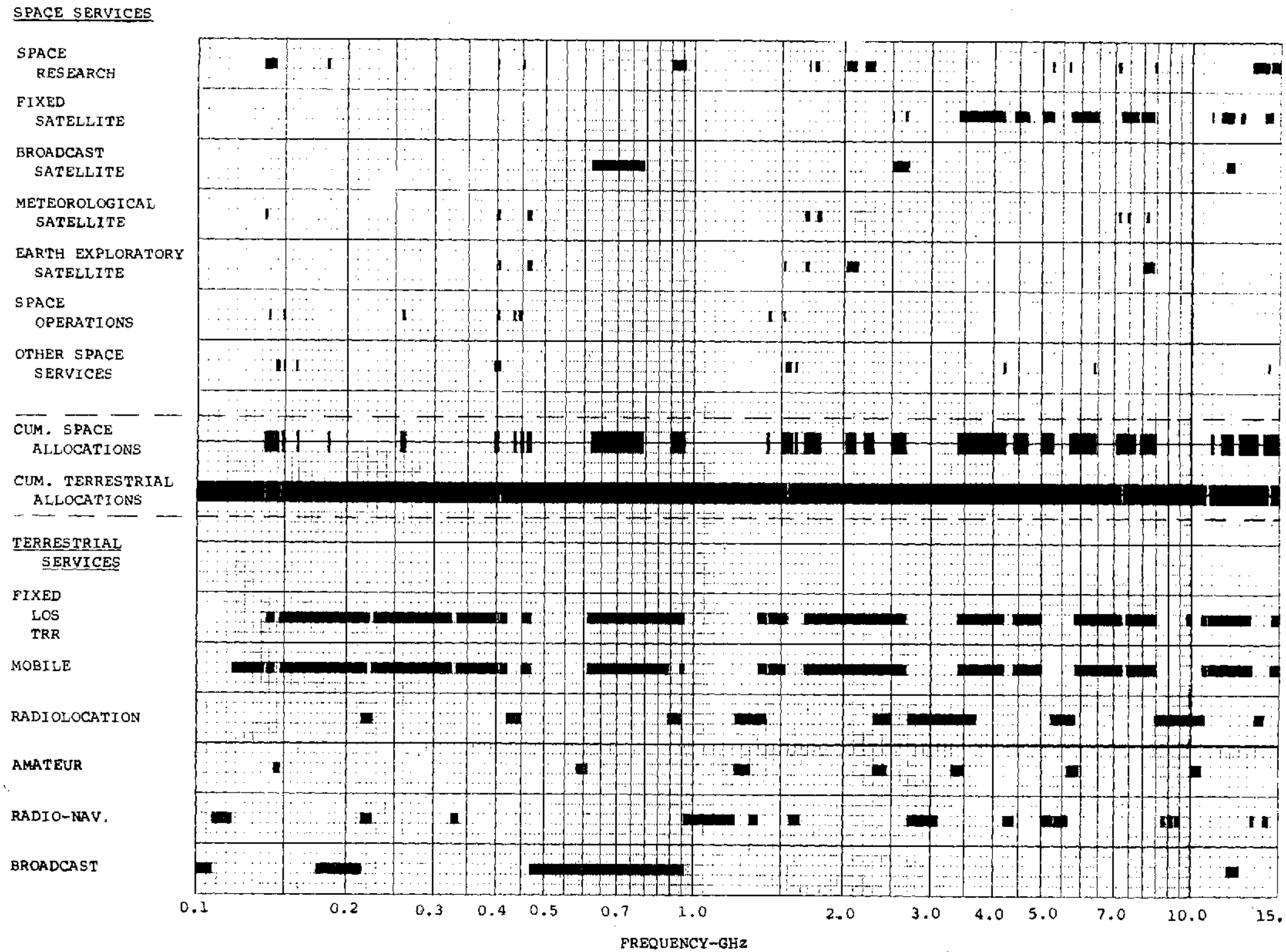



Figure 3-1 COMPARISON OF SPACE AND TERRESTRIAL FREQUENCY ALLOCATIONS

schemes, modulation and multiplexing techniques, data rates, redundant transmission schemes, antenna characteristics, passbands, filter techniques, transmitter power, etc., must depend on the description of the noise environment.

At the present time, little data is available on the nature and levels of man-made noise at orbit altitudes. (While there may exist extensive military programs resulting in such information, the scope of these programs as well as their results is entirely unavailable for unclassified use). The information available for non-military purposes derives from extrapolations of terrestrial man-made noise data; interference conditions encountered by orbiting spacecraft; a small number of man-made noise data collection experiments placed on satellites; and predictions resulting from mathematical models.

The currently available data on terrestrial emitters is extensive for some geographic areas and frequency bands and sparse or non-existent for others. The forms and types of data are very diverse, so that even for those bands and areas which are "well-covered", the diversity of data from different sources reduces the value of the whole. Both empirical and "reportorial" data have been generated.

- "Reportorial" man-made noise data is information collected by regulatory and other cognizant agencies regarding the characteristics of transmitters and

transmissions. Collections of such data, or data bases, are maintained by such agencies as the Federal Communications Commission (FCC), Electromagnetic Compatibility Analysis Center (ECAC), Interdepartment Radio Advisory Committee (IRAC), and the International Telecommunications Union.

o Empirical data sources include reports of studies and experiments which survey specific geographic areas (typically urban) for specific frequency bands or channels. The methods of data collection, measured characteristics, and thoroughness of documentation vary widely for the various studies and experiments. (Among such data are reports of only four experiments which have used earth-orbiting data collection platforms).

The existing environmental data bases are, for a number of reasons, inadequate for the purpose of predicting the man-made noise process <u>at a satellite location</u>. The FCC, IRAC, and ITU files are administrative files, used in the main to record frequencies, users, and a few nominal characteristics (e.g., power, modulation) of authorized transmitters. The ITU file, a prime source of worldwide environmental data includes only unclassified information and only that data which the participating countries supply. It is a frequency "registration", instead of an operating frequency file. That is, there is no guarantee that

the frequencies recorded for users are being employed, but rather that these frequencies have been registered for his use. The DOD/ECAC file, perhaps, most approximates completeness in terms of data required for extrapolation. Unfortunately, this file is limited almost exclusively to data regarding transmitters located within thecontinental U. S., and it is also known to be incomplete in many other respects.

The large uncertainties in cumulative mutual antenna coupling between terrestrial noise sources and satellite systems can result in signal prediction errors of at least the magnitude of the signal range between completely acceptable receiver performance and unacceptably degraded receiver performance. This amount of uncertainty makes it extremely difficult to arrive at an interference or no interference decision in the great majority of marginal interference cases.

There is not available a data file of the seasonal, diurnal, operational duty cycles (or on-off time statistics) of terrestrial transmitters. Without such data, such information as noise burst lengths, time between bursts, and impulse rates within bursts, so necessary to the communication system designer and compatibility engineer, cannot be predicted, assuming of course, that a suitable analytical method were available for combining the long and short duty cycle statistics of multiple noise sources.

As mentioned above, there are known instances of interference on operational satellite systems, and there have been four unclassified experiments placed on satellites for the specific purpose of RFI data collection. The OSO-IV satellite was used to develop data concerning RFI at 149.22 MHz; the LES-5 satellite collected RFI data for the 253-283 MHz band; LES-6 developed 290-315 MHz data; and Ariel III (British) took measurements at 5, 10 and 15 MHz. Of course, each of those experiments was not only very limited in frequency coverage, but was specific as to orbit altitude as well.

A number of additional interference data collection experiments have been proposed and designed to overcome the lack of data for specific allocated bands and altitudes, and one is currently included in the ATS program. One experiment was studied (for possible use with the Apollo Applications Program) which was to have relied on manual data acquisition from a 200 mile orbit.* This is the only known experiment which would have been "wideband" in that it could have collected data through a significant portion of the spectrum without restriction to specific currently allocated bands.

*Feasibility Study of Man-Made Radio Frequency Radiation Measurements from a 200-Mile Orbit, General Dynamics Report No. ZZK 68-007, February 1967.

At the conception of the AAFE Man-Made Noise Experiment, a considerable need was felt for definitive information on RFI in both current and potential earth/space communications bands to aid the frequency manager, system planner, and hardware designer in the prevention of communications degradation (primarily up-link). Planned and proposed experiments and techniques would not fully meet this need, and it appeared that the Advanced Applications Flight Experiment Program was the most logical arena to pursue the fulfillment of the need. Hence, an experiment could be devised to serve as a general candidate, in whole or in part, and to provide a baseline for consideration in flight programs. The ATS or SATS programs, or any of the numerous proposed space shuttle programs, could make use of such an experiment, or major elements thereof, as could earth exploration satellites or other programs. These considerations led to the concept of an RFI experiment in space.

# 4. PROJECT DESCRIPTION AND CHRONOLOGY

## 4.1 Purpose and Scope

It is felt that some value may be gained by providing a general record of changes and problems which were not originally anticipated during the course of this project. The remaining subsections of this section describe the major objectives of the project, discuss its organization and relate its chronology and work flow during its execution and describe the reasons for some of the changes and scheduling problems which were encountered. A final subsection summarizes the preceding three subsections and provides an overview of the project.

## 4.2 Major Project Objectives

The primary objective of the AAFE Man-Made Noise Experiment Project was to design a feasible experiment for the acquisition and processing of man-made noise interference data at earth orbital altitudes, to confirm the results of analytical studies concerning radio frequency man-made noise at orbital altitudes. It was further stated that the measurements of the amounts and types of noise in frequency bands of interest could allow the allocation and utilization of frequencies to be optimized and would also contribute to the engineering objective of optimizing flight receiving systems.

A second objective of the project was to design and fabricate a noise measuring receiver which would demonstrate the feasibility of the experiment designed under the project. The

sensitivities, bandwidths, and frequency ranges of this receiver, as well as its control and output techniques were to be such that meaningful levels and types of signals could be measured and characterized. The receiver was not to be designed for a specific platform, nor was it intended to be a "flyable device", but was rather intended as a demonstration model to prove in the laboratory the feasibility of a receiver with its weight, power, and other technical characteristics for such a space mission.

## 4.3 Project Organization

This project was directed under the Advanced Applications Flight Experiment (AAFE) program. The AAFE program is directed to the development of a series of experiments in a wide variety of disciplines which will be available to the future investigator for adoption to his program. AAFE experiments are intended to be developed to the point where their feasibility is demonstrated and their general constraints and characteristics are well defined.

The plan and schedule for this project defined a four phase effort. (During the course of its execution original phasing distinctions and chronology were obscured by the necessity for parallel work on three of the four phases simultaneously, and by the substantial reduction of the fourth phase).

Phase I of the project was defined as the experiment definition phase. During this phase, as many of the experiment alternatives as practical were to be examined, and time, cost, scientific payoff, and availability of the necessary technology was to be

considered for the various experiment parameters. Analyses were to be made of the trade-offs involved and the rationale for selection between alternatives was to be defined. The result of the first phase was to be a clear definition of the objectives of the man-made noise experiment and the recommended values for the parameters necessary. Specific tasks relating to and included in Phase I were:

- A literature search
- Frequency band selection
- Orbital altitude selection
- Selection of interference characteristics to be measured
- Satellite/platform study
- Spatial resolution study
- Frequency scanning/sampling trade-off study
- Antenna trade-off study
- Terrestrial equipment requirements study
- Prediction of interference levels to be encountered and measured

According to the original schedule, at the end of Phase I most of the important parameters defining the experiment were to have been analyzed, and recommended values were to have been selected.

Phase II was the system design phase. During Phase II, the performance requirements as identified in Phase I were to be translated into a system design to identify and describe specific items of hardware necessary for the achievement of the experiment's objectives. During this phase, both space and ground segments of

the experiment were to be considered as was the interface between the experiment and typical NASA telemetry and command systems. Special requirements for command and telemetry functions were to be identified during Phase II.

During Phase III, the instrument design and fabrication phase, the detailed design and fabrication of the noise measuring receiver and its associated control unit were to have been accomplished. The main emphasis of Phase III was the design of an interchangable front-end, modular receiver and the fabrication, for demonstration feasibility, of a one band receiver employing this concept. Two alternative methods for designing such a measurement system were considered feasible and were presented in the original proposal for the project. One was a tunable IF type which covered in 100 MHz steps, with multiple converter modules, a frequency range of nominally 700 to 1700 MHz. The other receiver originally proposed was a synthesizer-tuned type which used a stabilized tuner covering approximately the same frequency range.

Phase IV was entitled the verification test and documentation phase. During Phase IV, the prototype noise measuring receiver system was to be tested to verify its conformance to design specifications, to assess its performance, and to establish and refine the operating criteria for such a system. Computer programs written to manipulate and analyze the data also were to have been tested and debugged during Phase IV. Finally, the end results of the work performed under the contract associated with the project were to be summarized and documented in appropriate form.

The tasks to be undertaken in Phase IV included the following: a definition or model of the environment with the complexity adequate to provide an operational or worst case environmental simulation for test purposes, the conduct of test predictions to estimate the overall effectiveness of the tests; the development of a performance test plan to simulate the operation of the receiver in a spacecraft; and the formulation of computer programs to manipulate the data received from the spacecraft and tabulate the results.

Figure 4-1 depicts the original schedule for this project as proposed. It is worthy of note that as briefly as four weeks after the commencement of work under the project, the need for significant changes to the original work flow and to the hardware objectives of the project were becoming evident. Also, prior to the completion of the Phase I period (i.e., 13 weeks into the project) considerable modification had been actually accomplished and contract modifications as well as significant schedule changes were in progress.

## 4.4 Project Execution

As stated above, the original project work flow schedule (as shown in Figure 4-1) was modified extensively in light of evidence growing out of the Phase I studies which indicated the need for considerably different experiment concepts and hardware than those which had originally been proposed. For example, the study entitled "Frequency Band Selection" was to have resulted in the statement of the specific band of approximately 1 octave for

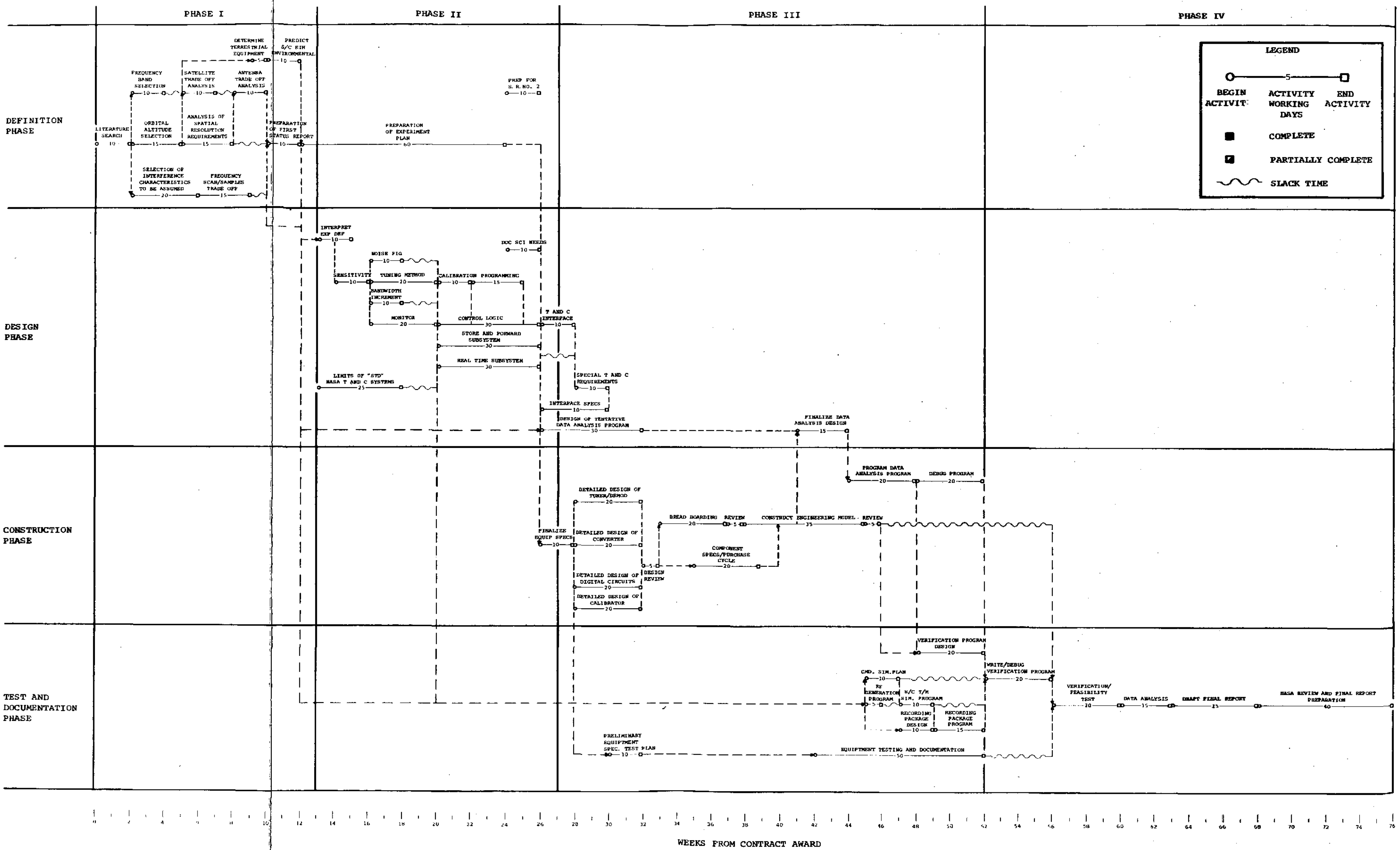



Figure 4-1. Proposed Work Flow Diagram

the hardware which was to have been fabricated; instead, this study resulted in the statement that no particular 1 octave band within the 100 MHz to 12 GHz range was particularly well suited viz a viz any other band in that range for such an experiment. The study of spatial resolution led to a considerable amount of simulation effort which resulted in the determination that the convolution of antenna patterns between the transmit and receive antennas could be a major problem in resolving the terrestrial emitter location. This led to the extension of the antenna trade-off analysis in order to investigate the possibilities of sidelobe blanking and other schemes which could reduce or eliminate such problems. It also led to an entirely new consideration of the possibility that low gain antennas would be more suitable for the experiment than moderate gain fixed aperture types such as had been originally considered most feasible. The study of antennas was complicated as well as by the conclusion that the wide band range for the experiment dictated that the antennas used would have to be of greater than 1 octave bandwidth.

As a result of the outcomes of the Phase I studies, work on a "new" receiver design had been begun and considerable simulation work was performed in connection with spatial resolution and antenna selection.

By the 27th week of the project, the contract under which it was being performed had been modified by the contracting officer's technical representative to specify the wide band or wide dispersion receiver. Negotiation between NSL and its

hardware subcontractor were carried out and resulted in a hardware subcontract with an 11 month design/construction period instead of a 6 month fabrication period which had originally been proposed and planned. The subcontractor felt the need for the extended design and construction phase because none of the preliminary work on the design (which had been carried out by the subcontractor for the originally proposed receivers prior to the project) had been yet completed.

The original terminal date for the project was retained at the time of the initial contract modification through the reduction of Phase IV effort and the reallocation of Phase II and Phase III tasks to accommodate the increased receiver design and construction schedule and to permit maximum concurrent task performance by the prime-and sub-subcontractors. By the 27th week of the project, the desirability of having the "new" receiver had come to outweigh by a considerable amount the desirability for extensive verification and testing of the hardware and the design concept. It was realized that the most important element of the experiment would be the spaceborne segments thereof, the nucleus of which would be the data collection and measuring receiver. Hence, maximum effort was devoted to the creation of a receiver with suitable performance characteristics.

The original 18 month period of the project did, however, require modification as the result of parts procurement problems and unanticipated receiver debugging problems incurred during the latter portion of the receiver design and fabrication subcontract.

Because the sechedule for the project was relatively arbitrary and a flight experiment was not dependent upon the schedule for the project, the "stretch out" could be accommodated with relative ease, and appropriate contract modifications were negotiated without difficulty. The final period of performance for the project was 23 months.

Table 4-1 outlines the actual work flow which occurred under the project as described in the various progress reports and other pertinent matters generated during the course of the project. From Table 4-1 it may be seen that a number of efforts were carried out which were not originally scheduled or identified as specific tasks, and it will also be seen by comparison with Figure 4-1 that the originally named tasks for the project were altered or eliminated in the actual performance. As stated, these changes were necessitated by the modifications and scope growing out of Phase I.

The subcontract arrangement whereby the demonstration hardware was designed and built by the Watkins-Johnson Company is worthy of some explanation. The original intent was that personnel of the Watkins-Johnson Company would work in conjunction with NSL personnel to develop the necessary demonstration hardware under a work order arrangement which would provide for purchase of the W-J personnel's time. However, when the new receiver was defined as a result of the Phase I studies, it was felt necessary to enter into a firm contract which would assure the necessary development and control costs. Hence, W-J was requested to bid on a

TABLE 4-1

AAFE MAN-MADE NOISE EXPERIMENT PROJECT
PROGRESS SUMMARY

| | |
|---|---|
| March 1972 | Literature Search commenced. |
| April 1972 | Literature Search completed.<br>Experiment Definition Studies begun, including:<br>Frequency Band Selection,<br>Interference Characteristics<br>Spacecraft Requirements |
| May 1972 | Experiment Definition Studies continued, including:<br>Spacecraft Requirements;<br>Interference Characteristics;<br>Spatial Resolution Techniques;<br>Scanning, Sampling & Bandwidth Trade-offs;<br>Antenna Requirements and Trade-offs;<br>Receiver Performance Characteristics & Design Concepts<br>Frequency Band Selection. |
| July 1972 | Interference Characteristics Study continued.<br>Antenna Trade-off Study completed.<br>Simulation Model developed (orbital mapping).<br>Terrestrial Emitter Population Study.<br>Experiment Receiver Draft Specification prepared.<br>CDSC Initial Design begun. |
| July 1972 | CDSC Fabriacation begun.<br>Receiver Specification revised.<br>Demonstration Receiver Design continued.<br>Experiment Plan Draft begun.<br>First Phase Status Report drafted. |
| August 1972 | CDSC Fabrication continued.<br>Interface Requirements refined; "CDSC" changed to CDSC/TI.<br>Subcontract Negotiation begun.<br>Experiment Plan Draft continued. |

TABLE 4-1 (CONT)

AAFE MAN-MADE NOISE EXPERIMENT PROJECT
PROGRESS SUMMARY

| | |
|---|---|
| September 1972 | Subcontract Negotiation continued.<br>Experiment Plan Draft continued.<br>Problem Area Studies, including:<br>Determination of Optimum Antenna Characteristics;<br>Determination of Optimum Data Processing Techniques<br>CDSC/TI Fabrication continued.<br>Subcontract Negotiation continued. |
| October 1972 | Subcontract Negotiation completed.<br>Demonstration Receiver Design begun.<br>CDSC/TI Design and Fabrication continued.<br>Problem Area Studies completed.<br>Schedule revised. |
| November 1972 | CDSC/TI Design and Fabrication continued.<br>Draft CDSC/TI Specification prepared.<br>Experiment Plan continued, including:<br>Experiment Operational Procedures study. |
| December 1972 | CDSC/TI Status Indicator fabricated.<br>CDSC/TI Design and Fabrication continued.<br>Telemetry Systems Standards reviewed.<br>Demonstration Receiver Design & Fabrication continued. |
| January 1973 | CDSC/TI Design and Fabrication continued.<br>Experiment Plan Preparation continued.<br>Demonstration Receiver Design & Fabrication continued. |
| February 1973 | CDSC/TI Design & Fabrication continued.<br>Experiment Plan Preparation continued.<br>Demonstration Receiver Design & Fabrication continued.<br>ATL MMN Experiment Report prepared. |
| March 1973 | Experiment Plan submitted.<br>Phase II Technical Report submitted.<br>Experiment Data Processing studied.<br>CDSC/TI Fabrication continued.<br>CDSC/TI Drawings revised and updated.<br>Demonstration Receiver Design & Fabrication continued. |

TABLE 4-1 (CONT)

AAFE MAN-MADE NOISE EXPERIMENT PROJECT
PROGRESS SUMMARY

| | |
|---|---|
| April 1973 | CDSC/TI Checkout and Test begun.<br>ADP Documents studied.<br>Demonstration Receiver Design & Fabrication continued. |
| May 1973 | Data Processing & Storage Requirements studied.<br>Demonstration Receiver Test Plan studied.<br>CDSC/TI Fabrication continued.<br>Threshold Performance Study initiated.<br>Demonstration Receiver Design & Fabrication continued. |
| June 1973 | Threshold Performance Study continued.<br>Data Processing Program Designs continued.<br>Final Report Data Collection begun.<br>Demonstration Receiver Design & Fabrication continued. |
| July 1973 | Threshold Performance Study continued.<br>Performance Specifications reviewed.<br>Report Materials reviewed and edited.<br>Demonstration Receiver Design & Fabrication continued. |
| August 1973 | Receiver Specification Interface Requirements modified.<br>Receiver Test Plan outlined.<br>Report Materials reviewed and edited.<br>Schedule Revision initiated.<br>Demonstration Receiver Fabrication continued. |
| September 1973 | Receiver Specification Interface Requirements further modified.<br>Demonstration Receiver Debugging undertaken.<br>Receiver Evaluation Data Processing studied.<br>Report Text Preparation begun. |
| October 1973 | Demonstration Receiver Debugging continued.<br>Report Text Preparation continued.<br>Scheduling and Liaison pursued extensively. |

TABLE 4-1 (CONT)

AAFE MAN-MADE NOISE EXPERIMENT PROJECT
PROGRESS SUMMARY

| | |
|---|---|
| November 1973 | Demonstration Receiver Debugging continued.<br>Receiver Test Plan Review completed.<br>Liaison pursued. |
| December 1973 | Demonstration Receiver Debugging completed.<br>Demonstration Receiver Subcontractor Performance Test completed.<br>Demonstration Receiver Performance Review held.<br>Schedule Revision initiated. |
| January 1974 | Demonstration Receiver Specification modified<br>Report Preparation continued |
| February 1974 | Demonstration Receiver - CDSC/TI integration initiated<br>Report Preparation continued |
| June 1974 | Demonstration Receiver - CDSC/TI integration completed<br>Demonstration Hardware Tests completed<br>Draft Final Technical Report completed |

specification of performance and physical characteristics of the desired receiver. The time required to consummate this arrangement was considerably greater than had originally been anticipated. Also, combining the hardware to be developed by W-J with that to be developed by NSL (i.e., the controller for the experiment receiver) required a separate development effort and considerable unanticipated attention to interface requirements in the form of specification. Nevertheless, the new receiver was developed within the budget constraints of the project and without undue extension in the original period of performance for the project.

## 4.5 Summary

The AAFE Man-Made Noise Experiment Project originally was planned as a sequential four phase effort encompassing tasks relative to the definition, the design, the construction, and finally the test and documentation associated with hardware and experiment concepts. The study and analysis performed during the first or definition phase of the project, however, resulted in a considerable modification to the remainder of the project. The requirements for demonstration hardware, and the scope of the experiment designed under the project were both increased. The original time frame for the project was retained until such time as difficulties in the fabrication of the demonstration hardware resulted in a necessary extension of the period of performance for the project. The extension requirements resulted mainly from difficulties in obtaining components for the demonstration receiver for the project and also in part from difficulties in debugging the receiver after its design and initial fabrication.

## 5. EXPERIMENT OBJECTIVES

A summary of major AAFE man-made noise experiment objectives is presented in Table 5-1. The overall objective of the experiment is to result in the creation of man-made noise characterizations for orbital altitudes which will provide useful information for those involved in frequency allocation and frequency management, for designers and analysts of communication links, particularly earth-to-space communication links, and for those involved in the creation of interference models. The last objective may, in the long run, be the most important one for the experiment. If, through this experiment, means can be found to create valid and reliable interference models, then the need for future spaceborne data collection platforms of this type may be obviated. The experiment will be placed in an orbit whose characteristics will permit it to "see" at least 99% of the populated area of the earth and, over a period of time, to view any area seen at any time of day (unlike the sun synchronous orbits). The space segment will collect data over a 2:1 altitude range from nominally 660 to 1400 kilometers above the surface of the earth and with the prescribed orbit it will repeat its ground track within tens of kilometers within 1 month or less. The hardware on the spacecraft will provide relatively sensitive measurement capabilities to permit the measurement of emanations from the great majority of intentional terrestrial emitters which can cause interference

# TABLE 5-1

## AAFE MMN EXPERIMENT OBJECTIVES

GENERAL - Obtain orbital man-made noise characterizations for use in:

1) Frequency allocation planning;
2) Communication link design;
3) Interference model testing.

SPACE SEGMENT - Establish an RFI data collection platform to:

1) See 99% of the populated earth;
2) View any area at any time of day;
3) View over a 2 to 1 altitude range;
4) Provide "complete coverage" in one month or less.

DATA COLLECTION HARDWARE - Provide facilities to:

1) Measure scalar (full field of view) RFI levels produced by e.i.r.p. $\geq$ -38 dBW + 20 log $f_o$ (MHz), from 400 MHz to 12.4 GHz (e.g., +43 dBW at 12 GHz);
2) Measure vector (directional) interference levels from nadir or horizon produced by e.i.r.p. $\geq$ 3 dBW, from 3 GHz to 12.4 GHz;
3) Operate under full ground control through stored or real-time commands.

DATA PROCESSING - Using minimal dedicated ADP hardware and fixed size, predimensioned magnetic tape archive libraries:

1) Reduce, organize and store orbital RFI data;
2) Generate PFD maps for specified altitude, season, time of day, frequency and bandwidth;
3) Generate RFI amplitude-time statistics for either vector or scalar data, and provide statistics in tabular or graphic form.

at orbital altitudes, and it will operate under the direct control of the experimenter on the ground who can either store a sequence of operational commands or can initiate real-time commands from the participating earth stations during a spacecraft pass. The hardware can be conditioned to measure incident levels without respect to angle of arrival if these levels exceed a frequency dependent threshold, and interference considerably below that threshold can be measured through part of the measurement spectrum either from the nadir (directly beneath the spacecraft) or from the spacecraft horizon. The data processing concepts and techniques will make use of predimensioned and fixed size magnetic tape storage facilities for archive storage of experiment data. Its final output will exist as power flux density maps of orbit spheres for specified parameters in time and frequency, and as graphic and tabular listings of amplitude-time statistics are incident interference levels at orbit altitudes. In this way, the general objectives of the experiment will be met.

# 6. DATA EXTRAPOLATION AND EMITTER LOCATION

## 6.1 Introduction

The desirability of producing data in one orbital sphere which could be extrapolated to other orbital spheres was of prime consideration from the outset of this project. Study of previous Unclassified efforts in this area led to the conclusion that, to date, there has been provided little data which would be of value to the user of any but the specific orbits where such data was collected.

The importance of extrapolation was considered to be based on the need for overall utility of the information growing out of such an experiment. It was recognized that the placement of an interference data collection experiment in orbit would be an expensive undertaking, and it was felt that the data resulting from such an experiment should be able to support a wide range of needs both in the present and for future applications. It was determined that, if data could be developed that would provide verification of models, provide valid statistical expressions concerning the important aspects of the interference environment for a wide variety of users, and provide specific measurements from a specified orbit with a specified data collection receiver, maximum utility would be attained.

The matter of resolution of ground emitters is directly related to that of extrapolation. The primary difference between the two terms is that extrapolation implies the projection of data

from one orbital altitude to another, whereas resolution implies the projection from an orbital altitude back to the earth's surface. These distinctions are used to separate discussions in this report. In the final analysis, extrapolation can be in either direction, and the resolution of emitters is part of the problem of extrapolation.

## 6.2 Potential Techniques

There are a number of techniques which can be used to determine the geographic location of an emitter from space. The most widely used technique is the use of directional pickup, wherein the directional gain characteristics of an antenna is used to provide a measure of the direction of arrival of detected energy. Using this technique, the antenna may be steered in order to seek out and track targets of interest, or it may have a fixed direction of orientation and simply rely on the "seeing" of emitters which pass through its swath of visibility.

Another frequently used technique in the resolution of emitters is that of the measurement and analysis of doppler produced by relative motion between transmitter and receiver. At the outset of this project, it was thought that doppler might well provide a feasible means for interferor location and some consideration was given to this possibility during the early course of study.

A third approach to the problem entails the "mapping" of the area of reception. This technique can provide information as to the areas of the sphere of coverage wherein the emitter is visible,

hence, the location of the emitter. An embellishment of this technique, and one likely to be more successful, entails the recording of amplitude as well as location of detection on the orbit sphere. With this technique, the patterns of amplitude from a given emitter are considerably more likely to produce knowledge of its location on the surface of the earth.

All of the techniques mentioned above were studied (in addition to several others, including modulation and interferometric techniques) for possible inclusion in the experiment designed under this project. A number of problems and limitations on the value and usefulness of each technique became evident. Study of the resolution in conjunction with the extrapolation problem eventually led to the definition of orbital and antenna requirements for the experiment.

## 6.3 Initial Simulation

At the outset of the project, simulation studies were undertaken toward determination of optimum antenna types and toward determining the feasibility of extrapolating data from one orbit altitude to another and to the earth's surface. As discussed in the following section of this report, the results of the early simulation work indicated severe problems if narrow beam or high gain antennas were used, and suggested the use of low gain "full field of view" antennas. From the standpoint of data extrapolation, the problem with the high gain antennas was that the presence of antenna sidelobes could produce simultaneous inputs with unknown values of $P_T$ and $G_R$, whose sum would give a false indication of the

level obtained in the antennas main beam and which, if extrapolated, would be entirely misleading.

The use of antenna directivity to provide resolution of the sources of emission is likewise hampered by a number of problems. Among these the frequency dependence of the high gain directional antenna and the presence of appreciable sidelobes in 3 dimensions are probably the greatest. (In addition, however, the requirements for platform stability in 3 dimensions can become appreciable with high gain antennas, and in the case of steerable antennas, the power for steering and maintenance of stability impose additional and greater problems). The sidelobes of the antenna, in conjunction with the sidelobes of the directional terrestrial emitters detected by the data acquisition system, will result in the existence of extremely complex patterns of amplitude distribution through the orbit sphere. In other words, the responses of the spacecraft receiver to each terrestrial interference source will be very heavily weighted by the 3 dimensional antenna gain characteristics and the antenna orientation of the terrestrial emitter, and as well by the gain and orientation characteristics of the spacecraft antenna. So extensive is this weighting that to have any meaningful utility, each data point must be tagged with the gain characteristics of the spacecraft antenna in 3 dimensions and with its orientation relative to nadir and track. Even then, the ability to factor out such characteristics for general data utility would require extensive and multi-level analysis.

The magnitude of the "gain convolution problem" resulting from the use of high gain antennas is shown by Figures 6-1 through 6-4. These figures show identical simulation models, except for the types of ground and spacecraft antennas postulated. Each of these 4 figures display received PFD with time, as the spacecraft traverses a direct overhead path on a single ground station. In all three cases, the ground station antenna is pointed directly at the point on the horizon at which the satellite initially appears, and the spacecraft antenna is pointed at its nadir.

In Figure 6-1, the spacecraft antenna is isotropic, and the ground station antenna has a sidelobe pattern of the CCIR reference antenna type. Because of the lack of sidelobes on both antenna patterns, a relatively smooth transition in receiver power flux density is made from a peak PFD as the satellite passes through the main beam of the ground station antenna to the time when the satellite passes out of sight of the ground station.

Figure 6-2 shows a somewhat more complex situation in which both the spacecraft and the ground station use the CCIR antenna pattern. This pattern clearly shows the response of the spacecraft antenna to be that which produces the higher amplitude response, as a result of the fact that the rangeis minimum when the spacecraft is directly over the ground station.

In Figure 6-3, the spacecraft antenna is of the CCIR reference pattern type while the ground station uses a simulated parabolic aperture of the sin X/X distribution. A pronounced

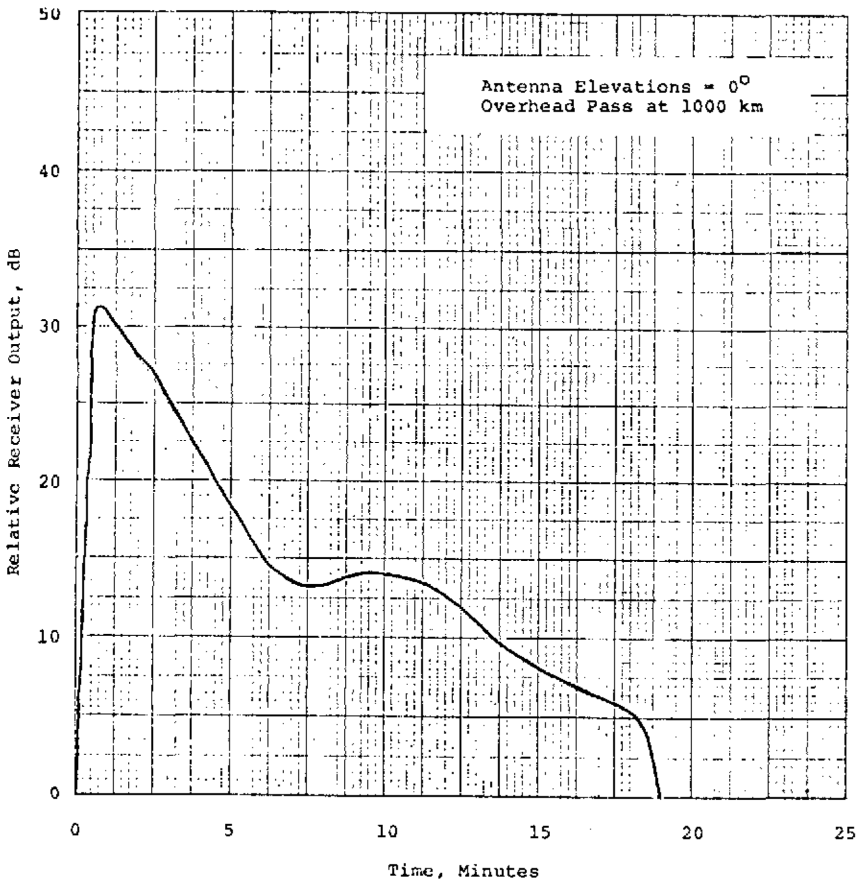



Figure 6-1 Modeled Receiver Response for Isotropic Spacecraft Antenna and CCIR Ground Antenna

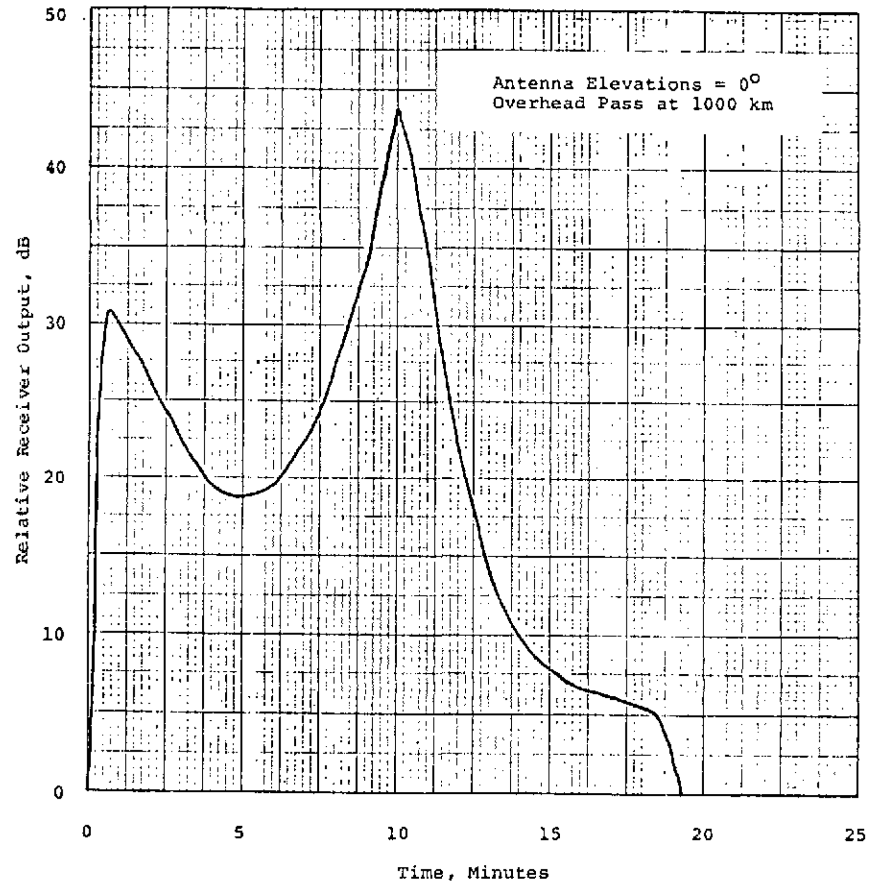



Figure 6-2 Modeled Receiver Response for CCIR Spacecraft Antenna and CCIR Ground Antenna

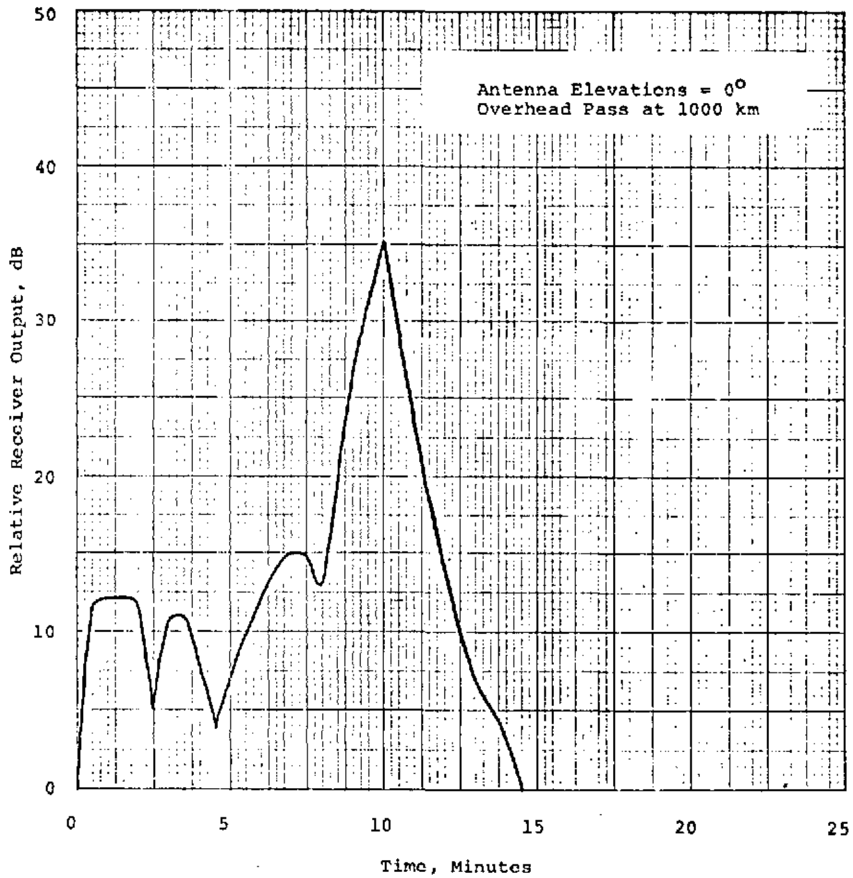



Figure 6-3 Modeled Receiver Response for CCIR Spacecraft Antenna and sin X/X Ground Antenna

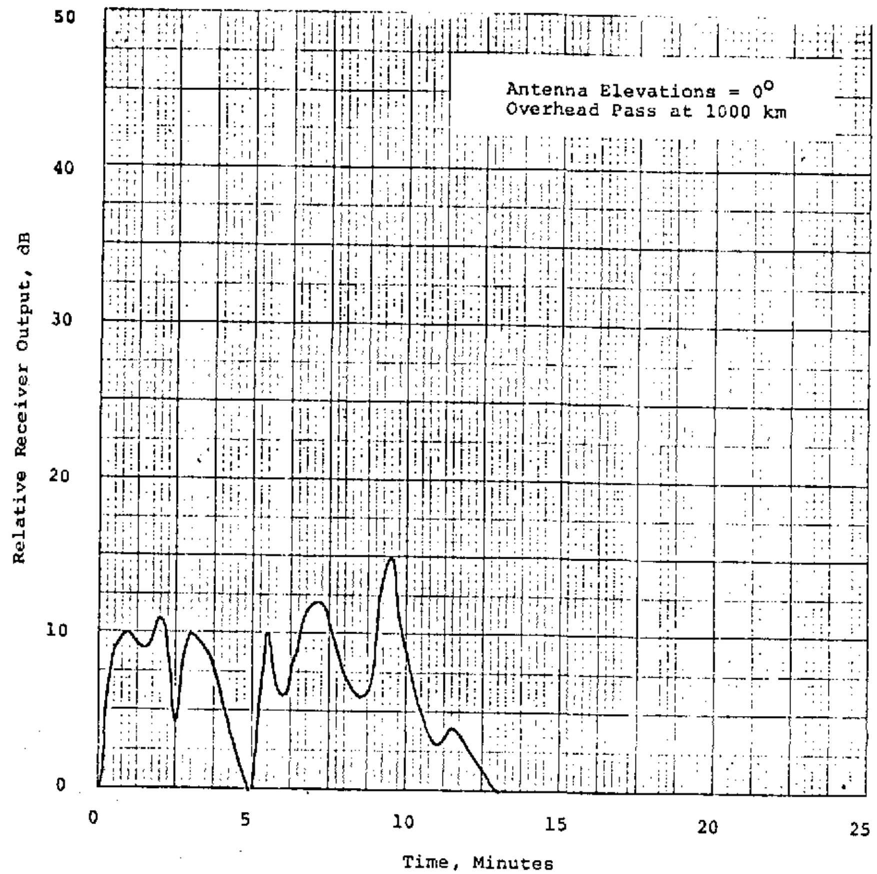



Figure 6-4 Modeled Receiver Response for sin X/X Spacecraft Antenna and sin X/X Ground Antenna

lobing effect is seen to occur as a result of the sin X/X ground station pattern. The maximum power received at the satellite no longer occurs in the main beam from the ground station but now occurs during interaction of the spacecraft mainbeam with a side-lobe of the ground station. It is important to note that the CCIR antenna pattern is simplified to the extent of eliminating all nodes and discernable lobes in the 3 dimensions and does not represent a realistic or realizable type of antenna. The sin X/X distribution however can be considered a relatively close approximation to actual parabolic antennas.

In Figure 6-4, the spacecraft antenna and the ground antenna both have the more realistic sin X/X distribution of gain as a function of off axis angle. This figure indicates a very pronounced lobing effect and a greatly reduced peak in the maximum power flux density which would be seen at the satellite. (It is important that the reader keep in mind that these responses represent a direct overhead pass and a single emitter).

## 6.4 Orbit Choice

The use of low gain antennas solved one of the perplexing problems which grew out of the simulation work, but with regard to the extrapolation problem, there was no immediage gain resulting from this decision. Additional simulation, however, led to the production of isogrammetric "maps" which generated equal level contours on the orbits sphere of data collection.

An area of the orbital sphere was mapped in response to a postulated terrestrial emitter characteristic. (The postulated stations are, in fact, existing elements of the Canadian Microwave Communications Network which operates at 2.075 GHz). Figure 6-5 is a map of the North American continent which shows 5 line-of-sight stations; these stations were used to generate simulated power flux density maps for a 1000 km orbit. The two maps resulting from this simulation are shown in Figures 6-6 and 6-7; they are identical with the exception of the spacecraft antenna patterns used for the simulation. Figure 6-6 was made using a sin X/X antenna pattern on the spacecraft simulating a 2-meter parabolic antenna operating at approximately 2 GHz. The resulting power flux density map shows no contour detail, and in fact a definite lack of information appears with respect to the sources of illumination for that map as a result of the interactive lobing of the terrestrial and pick up antennas. In Figure 6-7, a 5 dB full field-of-view coverage antenna was postulated for the spacecraft, and the contours produced in the simulated power flux density map very definitely show the expected contour shapes. A directed emitter on the earth's surface will generate a cone of energy which will intercept an orbital sphere with a "teardrop" shaped contour. These are very easy to distinguish in Figure 6-7; it is even possible to determine, from the shape of the contours, the line along which the emitter must lie and the direction that the emitter must lie in. Through examination of this "map" the existence of the transmitter numbered 65 will

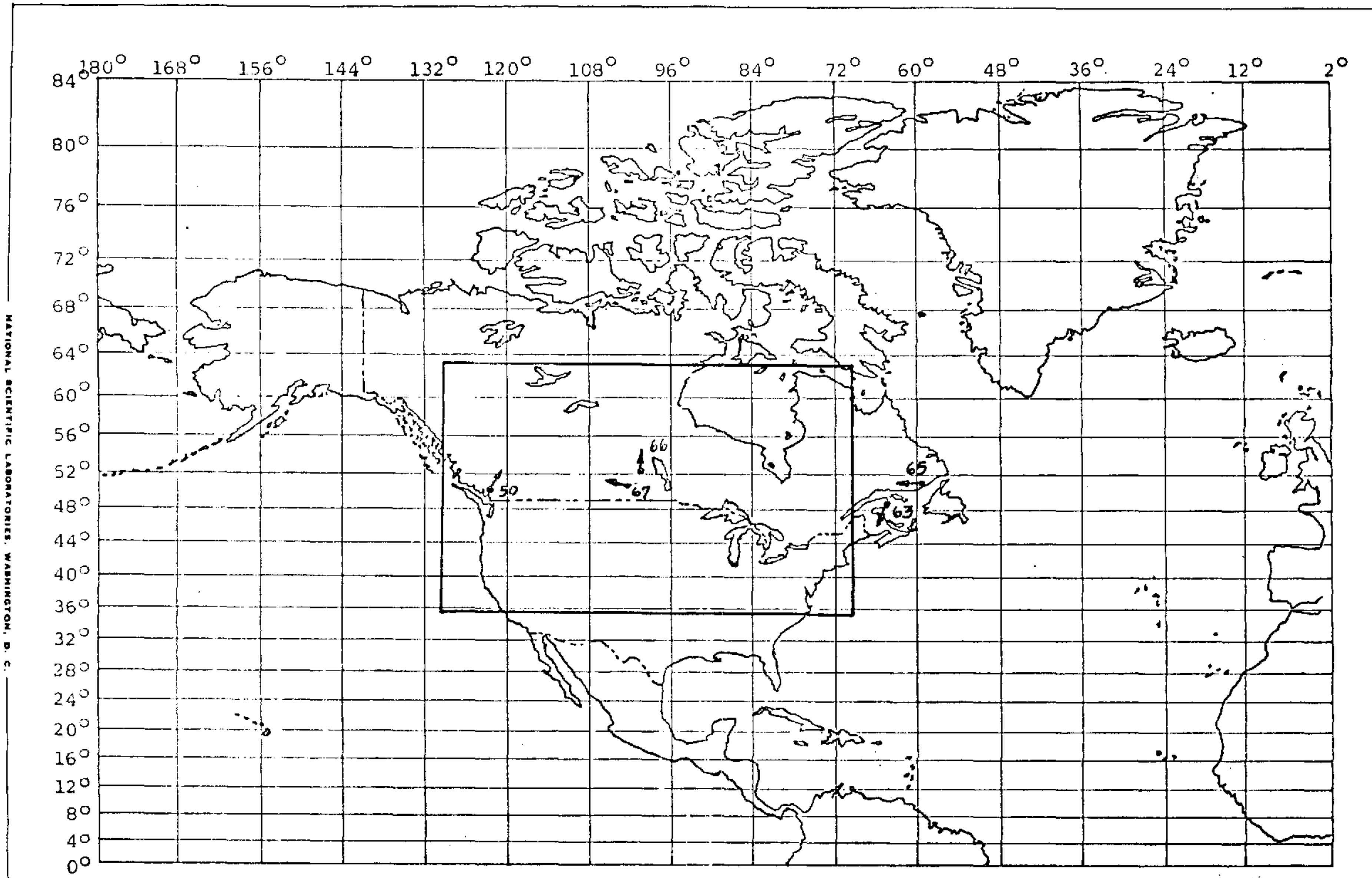
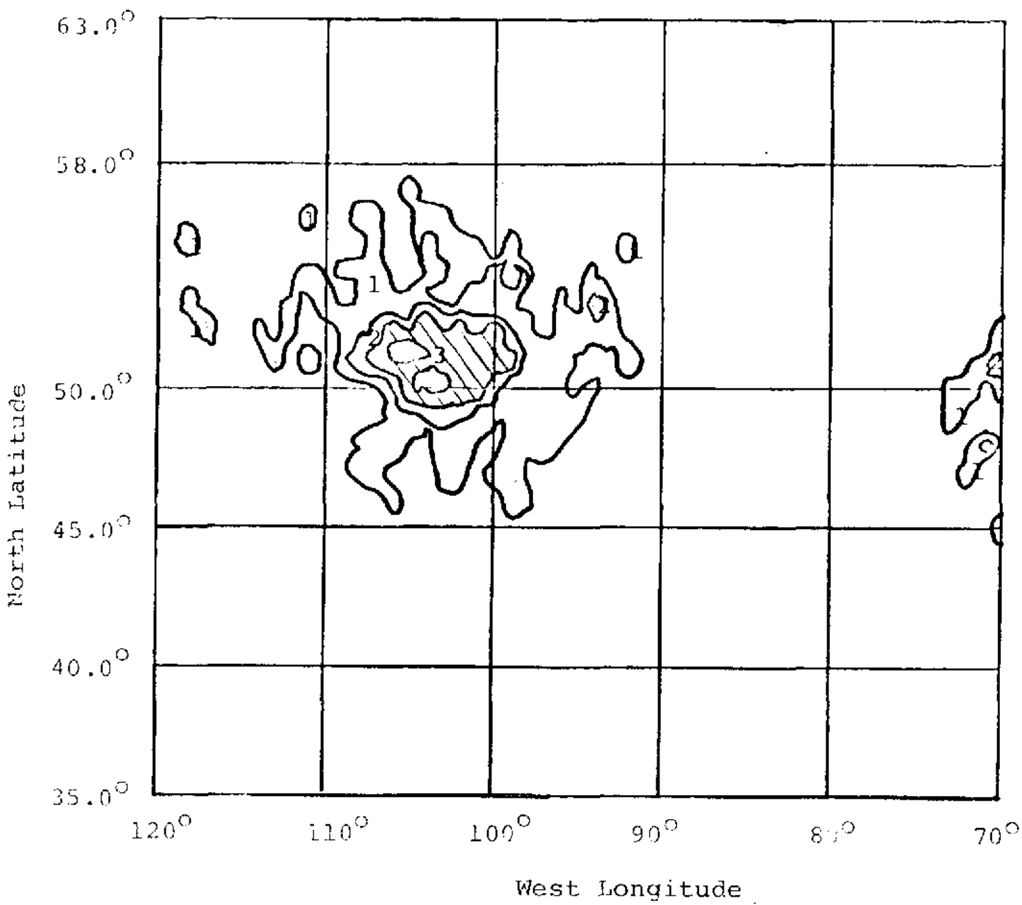


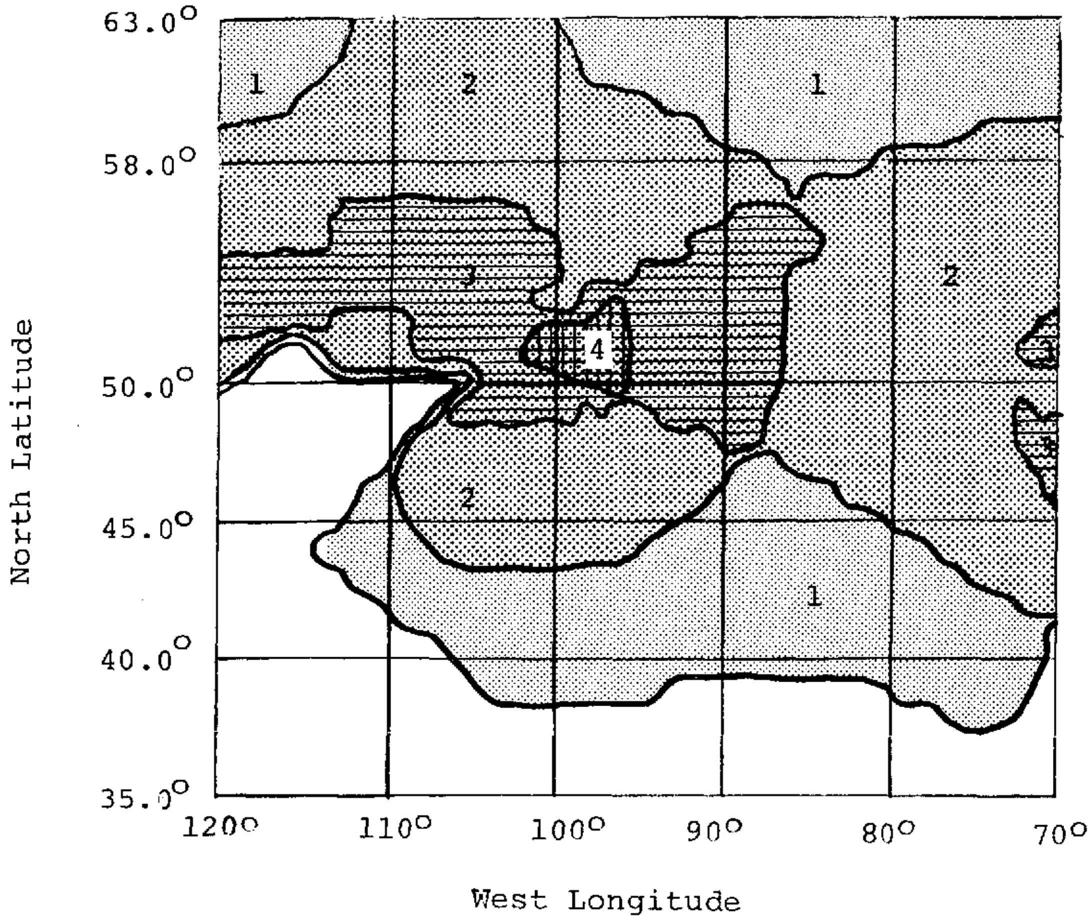

Figure 6-5 Ground Stations and Area Mapped in Simulation




S/C PARAMETERS

MDS: -140 dBW
Antenna: 2m - $(\sin X/X)^2$
Frequency: 2067-2067.2 MHz
Orbit: 1000 km, 63.5 deg. inclination
Ground stations No. 50,63,65,66,67
Each Contour = 2 dB

FIGURE 6-6 SIMULATED PFD MAP AT 10-0 km ORBIT, HIGH GAIN SPACECRAFT ANTENNA




S/C PARAMETERS:

MDS: -140 dBW
Antenna: 5 dB - Full Earth Coverage
Frequency: 2067-2067.2 MHz
Orbit: 1000 km, 63.5 deg. inclination
Ground Stations No. 50,63,65,66,67
Each Contour = 2 dB

FIGURE 6-7 SIMULATED PFD MAP AT 1000 km ORBIT, FULL FIELD OF VIEW SPACECRAFT ANTENNA

become readily evident, as will the existence of transmitter number 67, even though the energy from these two emitters is definitely interacting on the orbits sphere. Examination of Figure 6-6 and 6-7 lead to the conclusion that it is entirely unlikely for any meaningful interpretation to be possible in the case of multiple co-channel emitters if the spacecraft uses a high gain antenna, but inferences regarding sources and relatively accurate resolution thereof is entirely feasible if broadband or full field of view antennas are used for the collection of data.

The basis for data extrapolation as it evolved during the course of the first phase studies was essentially the establishment of a "virtual emitter" for each detected pattern and inference regarding projection of the output for each postulated virtual emitter to any altitude. If all of the energy passing the altitude at which the original data were taken were, in fact, detected or accounted for by the original data, then the accuracy of the projections on the basis of "virtual emitters" would have a reasonable degree of accuracy. In other words, if all real terrestrial sources of significant energy at the frequency of concern were accounted for by the PFD maps at altitude, then a reasonably accurate map could be constructed for another altitude on the basis of the virtual emitter population determined by the analysis.

In consideration of the relationship between the virtual emitter population and the actual terrestrial emitter population, it was realized that the more accurate determination, or a more

accurate set of inferences, could be made if data were available for two separate altitudes; if two PFD maps, each representing a given altitude, were available to the experimenter the interpretation of and relationships between equal intensity contours on the two maps could provide a far greater accuracy in establishing the sources of detected emanations. It was reasoned, then, that accurate extrapolation of data would be greatly enhanced if PFD maps were made available to the experimenter which corresponded to two altitudes rather than to one. The implication of this finding was initially that it would be highly desirable or necessary to place two independent data collection platforms in orbit; a scheme was devised, however, which appeared to provide the ability to obtain the desired data from two orbit spheres using a single data collection platform in a single orbit of a low order of eccentricity. The orbit finally chosen as that most suitable for the experiment was one which will operate over a 2:1 altitude ratio with a mean altitude of 1000 km. The study made to permit selection of orbit characteristics for the experiment was restricted to consideration of first and second order perturbations and resulted in "ball park" estimates of orbit performance and orbit maintenance requirements. However, it was felt that the basic feasibility of the concept of an elliptical orbit was demonstrated satisfactorily by these levels of consideration. The noteworthy characteristics of the orbit selected for the experiment include the "locking" of its line of apsides in the equatorial plain (i.e., the line of apsidies is co-incident with the line of nodes); its maintenance of the perigee altitude

$\pm$ 10% through its course from 33° South to 33° North; and its maintenance of apogee altitude minus 10% or higher from approximately 45° North latitude to 45° South latitude. Hence, over a considerable portion of the earth's surface, two orbit spheres could be mapped (within 10% of their nominal altitudes). Of course, for statistical purposes wherein the location of emitters or wherein the "two shell" data was not necessary, it would be feasible to take and to use data from any points on the postulated orbit. Additional orbit information is contained in the experiment plan appendix entitled "Launch and Orbit".

## 6.5 Choice of Antennas

With respect to the mapping of areas of reception and reception intensities, the first problem which was made apparent was the antenna gain convolution problem discussed above. Such difficulty could be readily resolved through the use of full field of view antennas; such antennas also would avoid the usual tuned antenna directivity/frequency or gain/frequency characteristics. From the standpoint of experiment objectives, difficulties relating to the use of the wide beam full field of view type of antenna consist primarily of experiment desensitization.

The resolution and extrapolation considerations which were involved in the development of this experiment were considerable; and of course they interrelated with most of the other major facets of the experiment. During the course of the studies relating to the experiment, the use of the wideband antenna types characterized by the conical logrithmic spiral, the crossed planar

log periodic, etc., was determined to provide a suitable trade-off where sensitivity is not overly critical. The use of such antennas will permit the development of power flux density maps and the comparison of modelled environments to actual conditions. For portions of the spectrum in which sensitivity is considered to be a serious limitation, complementary approaches to the development of meaningful data were proposed; those techniques entail the development of dimensionless statistics rather than power flux density maps. Hence, the mapping, the extrapolation, and the resolution of sources and patterns of radiation will be limited in this experiment to those emissions which are detectable through the use of low gain wide band antennas.

The consideration of data volume (i.e., the necessary ground storage and processing requirements to produce useful output) also weighted the use of the simple characteristic type of antenna such as the wideband frequency independent types, the importance of antenna orientation or position with respect to the earth would be minimized by the use of such an antenna, and data concerning such orientation would not be necessary.

## 7. TIME VARIABILITY OF RFI DATA

The inference of values of interference which would exist at times other than those when such interference was detected and measured is plausible only if the measured interference process is entirely stationary, or periodic with a known form of variation. In other words, the traffic pattern which produces the measured value of interference at the time of its measurement must be known if inferences are to be made as to the expected values at other times. Hence, it is feasible to extrapolate the measurements in time only with respect to use periods for the terrestrial transmitters which give rise to the data. While the traffic patterns for some classes of terrestrial emitters are well defined, the unknowns are great enough that extrapolation of data is not considered feasible until the true statistical performance for the terrestrial population will have been established through orbit altitude measurements. Therefore it is necessary to collect data from specific points in space and frequency "around the clock" to develop appropriate statistics. Hence, the use of an orbit for this experiment which is not synchronous with respect to the daily period of the earth or with respect to the earth's sunline is important.

In addition one of the major difficulties involved in the resolution of terrestrial emitters, and in the extrapolation of data in the other direction as well, is the necessity to assume that the input data is time stationary. Of course, in many instances, received interference will not be constant in time,

and may not display periodicity which can lead to its autocorrelation to generate a stationary picture. Such data points as may be detected which are, with respect to this experiment, random, will weight the final data to some extent, but should not detract from the presence and "visibility" of the stationary emitters which fall into view on a constant or periodic basis. Hence, the stationarity of all emitters, and all detected signals, is not necessary to permit the resolution of mapping of those which are stationary or periodic.

## 8. FREQUENCY COVERAGE

Of all interference data collection experiments proposed or carried out to date, the AAFE man-made noise experiment is unique in that it had a "carte blanche" with respect to frequency coverage. Whereas most experiments and data collection activities start with a specific band or with specific bands of interest, this project began with the initial task of selecting the optimum or most desirable frequency ranges in which to collect interference data for earth/space communications purposes. There were more or less arbitrary limits placed on the spectrum of coverage to keep the studies within reasonable bounds; these limits were defined in the original proposals and work statements as the range of frequencies from 100 MHz to 12.75 GHz. This 12.65 GHz frequency range is by far the greatest spectrum ever considered as a candidate for a single experiment.

The selection and use of frequencies is allocated by national and international authority on the basis of various types of users or "services". Typical of these services are the mobile services which involve non-stationary transmitters on the surface of the earth; the navigation and radiolocation services which entail the use of radar, navigational aids and radio altimeters, for example; and broadcasting services, the amateur services, frequency standard services, and space and earth space

services. These last services are those of import to the user of or designer of communications between satellites and the earth or between satellites. Allocations for up-link space service use exist throughout the spectrum considered for the AAFE man-made noise experiment. A study was performed of present and projected frequency allocations to determine the preferential bands for the experiment wherein, in a single band approaching an octave, there would be a large number of currently allocated or potentially valuable frequency bands which could find use in earth space services. However, the study revealed no preferential band for the experiment; however, the selection of a one-octave receiver appeared to limit the value of the experiment.

One factor considered important during the study of frequency allocations and band selection was the establishment and containment within the experiment of bands which could be used to collect "ground truth" data. In this instance the term "ground truth" is used to indicate the existence of a well behaved population which is known to be highly stable in all pertinent respects, and hence, is amenable to simple modeling for the purpose of testing experiment data. Comparison of actual experiment data (from the spacecraft) with the modelled output would provide a valuable check on the performance of the experiment.

The United States UHF television band from 470 MHz to nominally 800 MHz, and the Canadian fixed service band operating near 2075 MHz were found to provide the highly regulated, well known, and geographically well distributed populations of stable,

fixed location emitters for use as ground truth sources.

The lack of a single preferred octave band in the region from 100 MHz to 12.75 GHz led to the consideration of wider frequency bands for the experiment. During the course of the project, the original conceptual hardware was modified to permit operation over a greatly expanded frequency range, by the use of a novel design concept. This concept yielded a design which was amenable, in fact, to coverage of almost the entire band of interest.

The decision to limit the receiver to a low frequency of 400 MHz was based upon the existence of "entrenched" allocations throughout the 100 to 400 MHz region in the various terrestrial services, including military bands existing between 138 MHz and 400 MHz. It is noteworthy that the lower limit was, to some extent, arbritary, and that this limit could be reduced appreciably without great cost with the current general design of the experiment hardware.

At the outset of the frequency coverage study the frequency coverage of previous and other proposed experiments were considered; it was considered undesirable for the AAFE man-made noise experiment to duplicate the coverage of any already undertaken or proposed. On OSO-IV, data was collected from the single frequency 149.22 MHz to determine the source and nature of signals which had caused anomalous command performance in previous OSO satellites. The LES-5 collected data on man-made emissions from 253 to 283 MHz, a 20 MHz band in the military service allocation. The LES-6 satellite similarly collected man-made noise interference

data from 290 to 315 MHz. ARIEL 3, a satellite of the United Kingdom, performed radio noise measurements at 5 MHz, 10 MHz, and 15 MHz. The OGO satellites performed radio noise measurements at VLF frequencies. A considerable number of experiments have been carried out on the surface of the earth to collect man-made noise interference; these have been concerned with specific frequency bands of interest for the investigators involved in those experiments, and generally have been devoted to study of the broadcast allocations and the mobile services in the VHF/UHF ranges. A man-made noise measurement experiment is in the planning stages for use on the ATS-F satellite for measurement in the frequency range 5925-6425 MHz. An RFI receiver has been designed and fabricated by activities at the Goddard Space Flight Center for use on satellites. It is understood that this receiver may be placed on an ITOS class platform; its frequency coverage is in 3 discrete bands, namely 108-174 MHz, 240 MHz to 478 MHz and 1535-1665 MHz. As a result of the wideband concept developed for and during the project, it was unnecessary to specifically exclude any of the previously investigated bands; in fact, it was realized that insofar as the data collected or likely to be collected in these bands was specific with respect to altitude, geographic locale, etc., it would not be inappropriate to collect data in the same bands as other experiments with the orbit and other parameters specified for this experiment.

In summary, the investigation of frequency bands which would be most desirable through the 100 MHz - 12.75 GHz spectrum led to the conclusion that valuable data can be obtained through almost any band in that region; it was not possible or feasible to define the range or scope of uses for the data from this experiment (i.e., there were and are no specific data users in connection with this experiment) hence, the entire spectrum, or the great portion thereof, was selected as the appropriate area of study for a general data collection platform such as the AAFE man-made noise experiment.

## 9. DATA CONSIDERATION

Because of the frequent failure of other experiments to adequately handle data volume and manipulation problems, it was decided, at the beginning of the project, that this would have to be a prime consideration in the design of the experiment. If problems relating to data volume were entirely ignored in the early design, it would be likely that the baseline experiment could require continuous storage of a wideband analog channel corresponding to the optimum bandwidth for the experiment, and recorded in analog fashion at the ground station; this recording would, of necessity, have to be available on a random access basis at any time after the initial collection phase and would require dynamic range and resolution adequate to satisfy the needs of the experimenter. Hence, a continuously recorded and stored 100 kHz channel of greater than 60 dB dynamic range and resolution of 1 dB would be needed.

The analog recording of such a channel is technically feasible; however, it probably would require the accumulation of tape amounting to at least 4500 feet per hour. (This estimate is based upon typical instrumentation recorders which provide a 100 Hz to 75 kHz 3 dB passband response at 15 inches per second). Such a storage library would not, of course, be available for random access but would require sorting and positioning manually prior to access of specified periods of time or position. The digital recording of such a channel would be

infeasible: the sample rate would have to be greater than 200,000 per second and the resoultion would require a 7 bit code; yielding minimum bit rate of 1.4 megabits per second. The volume of data resulting from such a digital recording would be on the order of 1,512 megabits per ground station overhead pass.

The value of such a voluminous record would be small, and it is intuitively obvious that a considerably lower data volume could suffice. The determination of the minimum volume of data for the experiment was not, however, obvious to the casual observer at the outset of the project. Among the important considerations bearing on the volume of data to be recorded and manipulated were the visibility of the satellite, the desirability and feasibility on onboard recording, the feasibility of onboard data reduction techniques and data processing, the number of participating ground stations, the desirability or necessity for whole earth coverage, the frequency range for the experiment, the bandwidth desired for the experiment, the precession and recession and other pertinent characteristics of the orbit, etc. Directions and judgements made involving each of these experiment characteristics were influenced by its influence on the data volume.

Through consideration of necessary receiver bandwidth, attainable scan rate, and overall data collection schemes, the maximum number of data samples per second had been effectively established. The bandwidth of each receiver channel was to be 20 kHz; the maximum effective scan rate of the receiver was to be 200 MHz per second; hence the number of individual data samples

per second describing the input process to the receiver would be nominally 10,000. Although this value must be effectively reduced by the internal hardware constraints such as preamplifier band switching and receiver resetting during the course of each scan, it did represent a maximum feasible value for the hardware and hence was a value upon which down-link bandwidth, data rate, data volume could be established. With the effective data sample rate established, it remained only to determine realistic dimensions and scale for the individual data samples to define data volume, down-link bandwidth requirements, etc. Upon consideration, it was decided that each data point from the receiver should describe only an amplitude value. Operational frequency, time of acquisition, etc. should not be individually described in connection with each data point. In addition, it was established that a nominal 60 dB dynamic range for the experiment receiver would provide an entirely adequate value, and the use of 1 dB increments to describe the detected levels would be feasible and desirable.

The number of bits per sample required to describe each data point was determined on the basis of necessary resolution and other output data requirements: the dynamic range of 60 elemental values predicated a minimum of 6 bits per sample, and to provide additional levels outside the dynamic range of the experiment for use as "flags", an additional bit was added to the data. The seventh bit would permit a total of 128 levels of which a number could be used for flags to indicate the interruption of

normal amplitude descriptor samples or the insertion of other information, as well as indicating receiver/experiment status.

With 7 bits per measurement and a 10,000 measurement per second output rate, the down-link data rate was established at a maximum value of 70 kilobits per second, excluding data overhead. If the scanning rate of the receiver were reduced below that value, the output data rate could likewise be reduced, and each measurement time-interval increased.

The data volume which would accrue for processing continued to be considerable after the down-link data rate was selected. For example, at 70 kilobit per second, a continuous output results in a cumulative data storage requirement of $2.2 \times 10^{12}$ bits per year. High speed tape recording equipment is now capable of recording at the rate of 1600 characters per inch. Using such equipment, the tape requirement would be approximately 2000 feet per hour. Of course, if data is not taken continuously, a reduction in the overall storage volume can be expected; the determination of coverage requirements was then a consideration for the data volume problem.

On the basis of the previously mentioned orbit characteristics, Figure 9-1 is a map showing the STDN system as it existed at the time of the project. It appeared that USB stations

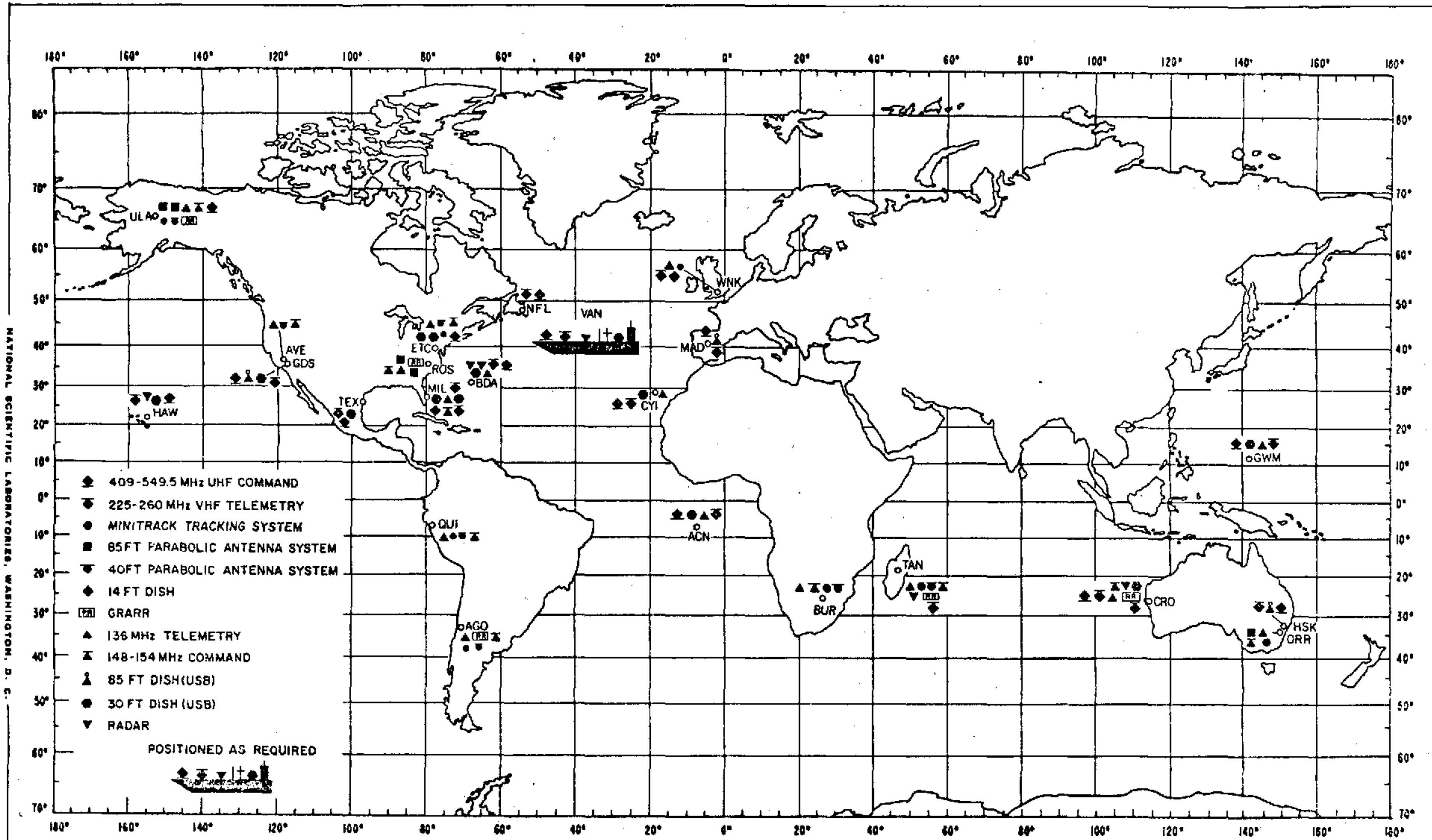



FIGURE 9-1 STDN CAPABILITIES (1972)

would be able to provide coverage of most of the populated earth's area outside the Sino Soviet Bloc nations. Further consideration however made it appear that the full time participation of all possible stations would be infeasible; the initial value to the experiment of data from 5 stations would be entirely adequate to establish the general utility of the experiment, and maps made from the 5 stations would be adequate to provide comprehensive coverage of a geographic region including the entire North American continent and a great portion of Europe. Figure 9-2 indicates the coverage attainable from the specified orbit with 5 participating STDN ground stations, namely: Fairbanks, Alaska; Goldstone, Calif.; Corpus Christi, Texas; Greenbelt, Maryland; and Madrid, Spain. Figure 9-4 indicates the visibility from each of these ground stations at the perigee altitude of 667 km, the mean altitude of the orbit, a 1000 km and the 1333 km apogee altitude of the orbit. The 1000 km coverage would be attained for all stations; the 667 km coverage could be expected to a latitude of 33° North; and the 1333 km altitude coverage could be expected to a latitude of approximately 50° North.

Coverage over the portion of the earth not included within the visibility of the 5 proposed ground stations is entirely feasible, through the use of an onboard recorder and the addition of a second down-link data channel of approximately 80 kilobit per second capacity. The use of a higher rate down-link channel for the prerecorded data channel is necessitated by the inclusion of "time of acquisition" flags in the data stream from that channel which are not necessary in the real time down-link data stream).

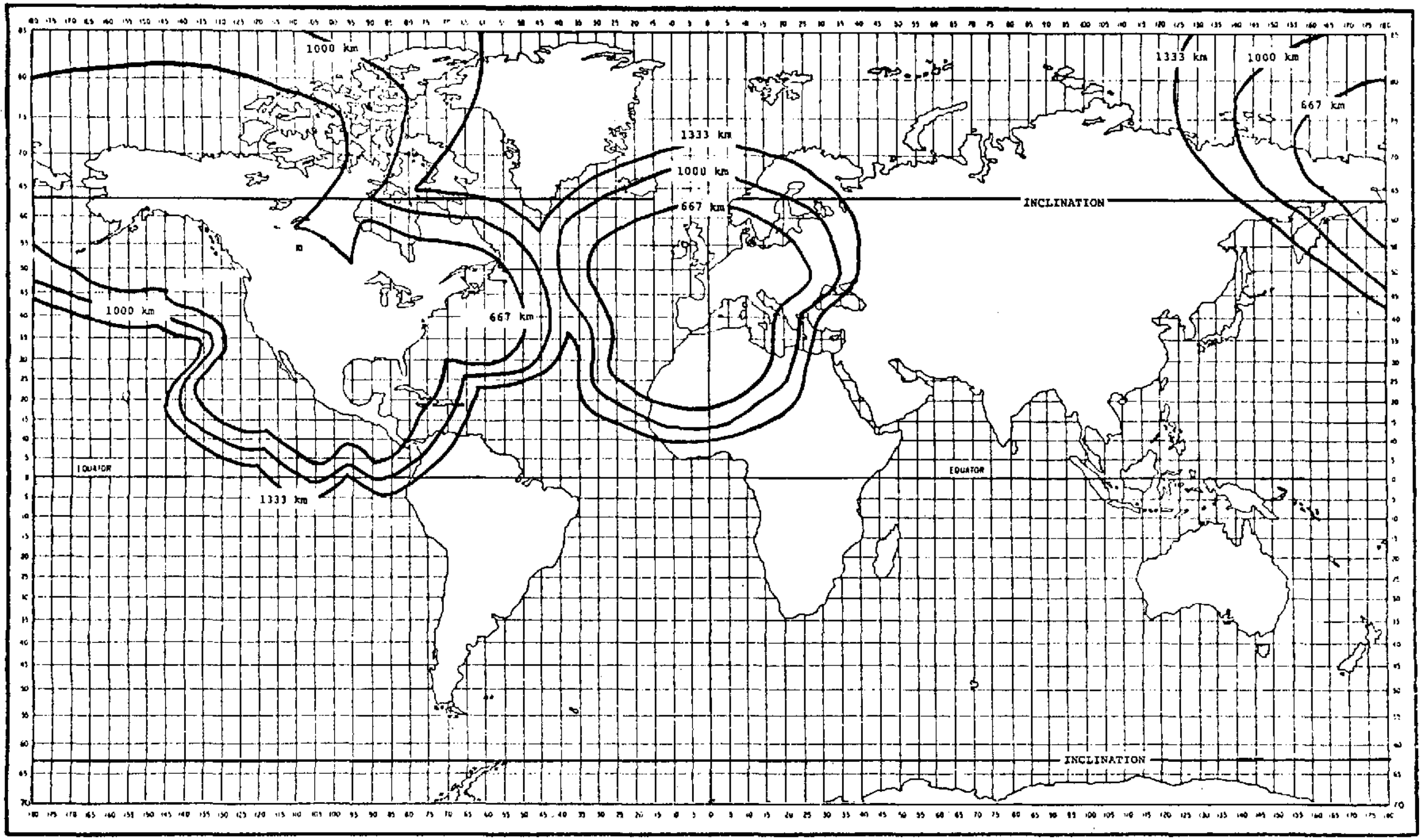



FIGURE 9-2 AAFE MAN-MADE NOISE EXPERIMENT SATELLITE VISIBILITY PLOT

As previously stated, if the 70 kilobit output of the experiment receiver were recorded continuously, the amassed data would amount to approximately $2.2 \times 10^{12}$ bits per year; if no "backside" recording or other out-of-sight data acquisition were employed, and if it is assumed that the 5 selected earth stations encompass approximately one tenth of the total land mass available within the satellite's tracking area, then approximately $2.2 \times 10^{11}$ bits would accrue during a one year period. This data accrual is exclusive of any bits added at the ground station or at the data processing facility for identification or additional flag purposes. The number of tapes which would be required to store the entire mass of data would be on the order of 700 per year, assuming 1600 characters per inch packing density. The continuous accumulation of this mass of storage would be infeasible for such an experiment, and of course the requirement would be one order of magnitude greater, that is, on the order of 2500 tapes per year, if full time data recording were attempted.

At this point, it is worth noting that the 70 kilobit per second down-link data rate is one which is considerably below that which would be required for an equivalent bandwidth using digital output with Nyquist sampling criteria. This is to say, steps had already been taken to reduce or minimize the mass of data at the input to the ground segment of the experiment. It is evident, however, that a considerably greater effort was required to produce a manageable amount of storage data. Two approaches were possible for this reduction: real time or near real time data processing could be accomplished to effectively

lump large segments of data into more manageable data point sizes, or summation and accrual techniques can be employed to provide a library of fixed size with statistical, rather than fixed data point significance. In the "Data Handling" Appendix of this report specific selections and rationale for them is discussed in some detail. Both methods of data management and reduction can be employed to compress data in the dimension(s) selected by the experimenter.

The final result of data volume considerations in connection with the AAFE man-made noise experiment was the creation of central, fixed size magnetic tape libraries for archive storage of reduced data which contains the accumulated statistics on levels encountered in addressable records which are identified by their spatial, spectral, and temporal characteristics; with the statistics updated throughout the course of the experiment so that the library is current at all times. Implementation of this scheme required the creation of a data storage library concept with a specified address hierarchy for acquisition, updating, and sequential storage of data. The number of libraries so dimensioned is not specified at the outset, but can be changed during the course of the experiment and can be modified as required should the requirements of the experiment change.

Within the library, the lowest individually addressable element is a frequency record. Each frequency record will contain a number of amplitude cells, a maximum and a minimum amplitude byte, and an overflow flag. The count of input data samples falling

within the boundary of each amplitude cell is the stored value for each cell. Values of the highest and lowest levels within the record are indicated by the maximum and minimum amplitude bytes. A flag is set when any amplitude cell count exceeds a maximum level; no further data is accepted in a record with such a flag, and the presence of the flag is signalled at the time of its occurrence to the cognizant operational personnel.

The frequency record associated with the experiment is bounded in time and in space by a location or address hierarchy set up to provide for the storage, retrieval and updating of the data with a minimum number of sequential storage area passes. Typically a library could store data by annual season, nominal altitude, geographic resolution area, diurnal phase and frequency. The size of a magnetic tape library in support of the experiment will depend upon the number of amplitude cells required per frequency record, the number of frequency records required for the library, and the "size" of the elementary geographic resolution period or "geo-bin", as well as the overall dimensions of the geographic area covered by the library. The geographic shape, or form, of an individual geo-bin, as envisioned for this experiment, will depend upon its geographic latitude boundaries: at or near the equator, it will closely approximate parallelograms (on a planar map) that at or near the inclination limit of the orbit (63.5°), it will appear to have curved boundaries if projected on such a map. The conceptual basis for such bins is to facilitate the data indexing and cataloging; there dimensions are, in fact, no less "regular" than any other readily defined

spherical surface apportionment. In effect, the creation and use of such pre-dimensioned data storage libraries consists of a data summation and accrual technique which should provide statistics of significance regarding the encountered levels in the individual cells by their various dimensional coordinates.

Prior to the recording of the data in these libraries, it will be feasible to reduce the initial input data by significant amounts. This process will take place either at the ground station or at the central processing facility associated with the experiment. The fundamental resolution dimensions of the experiment data can be expanded as required for the specific library to which the data is ultimately directed. Redimensioning in real time or near real time can take place by the acquisition and comparison of individual data points in succession which correspond to a given dimension. That is, if the fundamental 20 kHz resolution element is not required, the succession of data points which correspond to some larger frequency resolution can be collected as a succession and compared; the peak value of the resulting collection of data points can be used to establish the peak value of the expanded dimension data point. This process can be implemented for the frequency element, the geographic element, or the temporal characteristics.

In summary, the data volume considerations for experiments such as this which cannot rely on visual techniques (available to optical researchers and experiments), are significant. In order to bring the experiment to manageable bounds, a number of techniques were considered during the course of experiment development to inhibit the total volume of data associated with the experiment. These techniques provide for a fundamental resolution element which is considerably in excess of that likely to be used in all dimensions but available for use in any required dimension. The use of predimensioned data storage libraries for the collection of significant statistical samples was one of the fundamental data processing concepts. The importance of data line considerations through all phases of experiment development was clearly demonstrated in the considerations which led to the design of the AAFE man-made noise experiment.

## 10. THRESHOLD MEASUREMENT

Sensitivity was an important consideration from the outset of the AAFE man-made noise experiment project. Noise receiver performance goals as specified in the demonstration hardware subcontract negotiated under this project, required a worst case noise figure of 10 dB; actual performance of the demonstration hardware provided maximum noise figure of 11 dB. The equivalent noise level of the demonstration receiver designed and developed under the project is approximately -150 dBW per 20 kHz under worst case performance conditions (i.e., at 12 GHz). In fact, the noise performance of the demonstration hardware for this experiment is comparable to that of a typical fixed frequency terrestrial line-of-sight common carrier relay receiver. Initial consideration of sensitivity was limited to the RF noise performance of the experiment hardware.

The detection scheme initially specified for the AAFE man-made noise experiment receiver was a peak sample and hold detector, wherein the peak level of each 20 kHz measurement channel in the receiver during a sample interval would produce an output level. Two primary considerations resulted in the selection of this detector scheme: in an unknown signal environment, the peak detector will "bound" interference intensity, or levels that are being measured (e.g., if an impulsive type interference signal is present, the peak power measurement may be of more significant value in establishing the interference potential than any other characteristic), originally, consideration of the

experiment dictated simplicity and lack of complexity; a single detector was considered to be desirable from that standpoint. At the time of the detector function selection for the experiment receiver, little consideration was given to the effect of the detector on the "threshold performance" of the receiver. This topic was not addressed in any of our reports or study papers relating to the project and, apparently had not been specifically or individually studied by any previous experimenter whose reports were available to us. The fact that threshold performance would affect the quality of data from the experiment was recognized throughout the course of the project; a near state-of-the-art sensitivity had been specified (and paid for) in terms of swept frequency receiver performance; but we had not analyzed the "impact" of the detection and output data scheme on threshold performance through a great portion of the project.

During the course of the project, Dr. John Painter acquired the task of Contracting Officer's Technical Representative (COTR) and in that capacity he raised questions concerning the "threshold performance" of the specified receiver. As a result of his perceptive queries, the topic was considered more carefully and a number of conclusions were drawn with respect to the performance of the receiver in response to low level signals and regarding alternative detector schemes for use in connection with the experiment.

The threshold alluded to in the phrases "threshold performance" and "threshold levels" is the threshold of detectability or measurability. Hence, "threshold performance" implies receiver response to the minimum discernible input excitation, and "threshold levels" are the amplitude values of excitation producing such response. With excitation below the threshold of detectability or measurability, the receiver output measure indicates receiver internal noise levels. Excitation above the threshold of detectability produces an unambiguous increase in output levels, and positively indicates the presence of input at the receiver's tuned frequency. The actual threshold is ambiguously defined unless the time domain form of input excitation and the processing techniques prior to the final output are defined. This is to say that the minimum unambiguous increase in output levels is affected by input excitation form and output processing. The form of input excitation can be characterized as a monochromatic, a Gaussian, or an impulsive process.

Output processing in the man-made noise experiment receiver consists of band limiting, demodulation and digitizing. Five contiguous, band limited channels are simultaneously processed in this manner. The predetection passband for each "parallel" channel is 20 kHz. Demodulation, in this case, consists of IF envelope recovery, and creation of an amplitude value descriptive of the demodulator input process based on the envelope. Digitizing consists of converting the demodulator output amplitude value to an appropriate binary word which is fed to the receiver output

interface. The demodulation process is performed during intervals of fixed duration, and between each successive interval (for each channel), the demodulator is inhibited and its output appropriately reset to zero. The timing relationships between receiver tuning, demodulation intervals, and output control for the five "parallel" channels do not appear to weigh heavily on the threshold performance topic.

A key element of the output processing function, as regards the receiver's threshold performance, is demodulation. (It is important to understand that the term, "demodulation", as applied to this receiver, does not imply the usual intelligence recovery process. Rather, it connotes the generation of a measurement value to describe the IF signal during each measurement interval). A demodulator commonly employed in the measurement and characterization of interference, namely the peak detector function, was selected early during this project as one which provides an accurate indicator of the potential interference value of input phenomena, independent of their time domain forms. The output of this demodulator is a value indicating the peak level of the input process envelope in the IF passband during the measurement interval. In operation, the peak detector recovers the IF output envelope and remains charged at its peak value. The discharge of the peak detector is negligible throughout the measurement interval, but it is total between successive measurement intervals. Envelope recovery can be characterized by a piecewise linear or a quadratic detector response, either of which include receiver

input signal, internal noise, and cross-product (signal times internal noise) terms in their output processes. With any form of envelope detection, such terms are components of the output and must be considered in determining threshold performance.

The input signal and the internal noise terms of the envelope detector output expression are represented as second order quantities which maintain positive values at all times. The cross-product term, however, is capable of acquiring values with either polarity. By way of illustration;[1] the output of a piecewise linear detector can be expressed as

$$e_{f1} = em^2 + 2\, e_m e_n \cos\,(\theta_m - \theta_n) + e_n{}^2$$

where $e_n$ represents the noise modulation of the IF carrier, $e_m$ the signal modulation from the receiver input, and $(\theta_m - \theta_n)$ is produced by the phase difference between signal and noise. (The output of a quadratic detector contains similar terms

$$e_{f2} = e_m{}^2 + 2\, e_m e_n \cos\,(\theta_m - \theta_n) + e_n{}^2$$

In these expressions, the terms containing $(\theta_m - \theta_n)$ are capable of becoming negative. If either signal or noise is the "highly predominent" contributor at the detector input, the contribution of the $(\theta_m - \theta_n)$ terms to the output becomes negligible. For the case of the predominent signal, if the gain function of the entire receiver and the internal noise process are "known", the signal

[1] See Wainstein & Zubakov: Extraction of Signals from Noise, pg. 94 et seq.

term, $e_m^2$ can be extracted from the output of the detector and modified to provide an accurate measure of input signal level.

For the peak detector (of quadratic form, for simplicity) the output can be expressed as

$$e_p = \max\ [e_m^2 + 2\ e_m e_n\ (\theta_m - \theta_n) + e_n^2]$$

The peak detector output does not represent the sum of the maxima of its additive terms, i.e.,

$$e_p \neq [e_m^2] + \max\ [2\ e_m e_n (\theta_m - \theta_n)]$$

$$+ \max\ [e_n^2]$$

because $e_m$ and $e_n$ are independent processes in time. When the input signal is clearly predominant, the cross-product term ceases to be significant. However, when the receiver signal to noise ratio (which can be represented as $e_m/e_n$) reduces toward and below unity, the cross-product term can become highly significant; its magnitude or significance, however, during a specific period in the formation of the peak value, is not predictable (although the maximum value of noise during the period may be predicted through statistical analysis). Hence, this cross-product term detracts appreciably from the possible accuracy of measurement using a peak detector, unless em/en $>>1$, or $e_m/e_n << 1$ and the performance of the receiver as specified will not provide good measures of input signal levels at and near the "noise floor".

This basic finding is not supported by previous work on this specific topic; to our knowledge there has been none. Upon reflection, it is apparent that the demodulator function known as "peak detection" generally has no application for low-level (threshold) measurements. The standard interference measurement effort is not concerned with emissions so low in level as to be at or near the detection threshold in proximity to the source; the interference measurement apparatus is equipped with large order input attenuator, shielding, etc., to reduce fortuitous entry paths for the usually high-level "signals" to which it is exposed in the immediate vicinity of potential interferors. In our instance, however, the measurement apparatus is in the locale of the potentially disturbed apparatus; its "sensitivity" requirements are quite unusual. (Hence, the adequacy of the man-made noise experiment, for quantifying interference to near geostationary orbit receivers may be greater than for lower orbit links).

One possible value of the peak detector, aside from its value as a high level interference measurement tool, may be in the detection of low level signals (terrestrial interference). Whereas the envelope detector's cross-product term certainly produces irreducible ambiguity in the output, it may, however, tend to add to the band limited, discrete-period maxima so as to create threshold of detectability somewhat lower than for alternate demodulation processes. In this area, it is felt that the quantization, or digitizing process also specified in the receiver will be a strong influence. Variations in output level from

measurement to measurement (with the receiver "on the bench" and operating in its fixed frequency mode) without applied external excitation will indicate the statistical variance of band limited random Gaussian noise maxima during the specific measurement duration and as quantized to 1 dB increments. The rigorous modeling and determination of this variance has not been undertaken, but as a key element of the receiver's threshold performance, it has been studied to some extent. Preliminary lab tests have indicated that the noise floor ambiguity may be contained within a 6 dB range, and that the standard deviation of measurements would fall within a 2 dB range. It appears likely that contributions by the detector's cross product term (lacking in the noise-only case) might significantly affect the input excitation level at which the digitized output is raised unambiguously (e.g., 4 dB mean). Experiments might provide an empirical basis for prediction as to this possibility, but at this time, intuitive speculation is the sole guide in the matter.

Upon determination of the likelihood of ambiguity in output data from the receiver at and near the threshold, we considered means for increasing the accuracy of measurements resulting from this data. If the receiver were to operate in a static environment, post-collection processing might be used to improve threshold measurement accuracies. If this spectra of the potential interference signals were well defined, predetection filtering in the receiver could be used to enhance $e_m/e_n$. However, the environment will be very dynamic, and the nature of the experiment

precludes rigorous definition of the signals to be measured. The signal processing techniques frequently employed by meteorologists in the measure, or estimation, of signal parameters under unfavorable signal to noise conditions include autocorrelation detection, cross-correlation detection, signal averaging, and probability density function generation. Of these four techniques, three clearly are not applicable to the experiment designed under this project. The fourth, however, may find application both in the enhancement of near-threshold data value and in the resolution of high-level excitation time-domain form. This potentially valuable technique is that of post-detection signal averaging, or average signal detection.

On the basis of the detected signal model presented above the potential value of the average signal detector can be demonstrated. The average value of the internal noise modulation term; $e_n$, is zero because it is an unbiased random Gaussian process at its source and is not biased (away from zero mean value) by the modulation and band limiting functions of the receiver. As a result of this virtue, the cross-product term resuting from envelope detection, $2\ e_m e_n \cos\ (\theta_m - \theta_n)$, also maintains an average value of zero, irrespective of the mean value of the signal factor, $e_m$, in the term. Hence, the output of a (true) average detector consists of a signal term (whose operative factor is $e_m$) plus a nose term (in $e_n$). The output noise term maintains a consistent mean value, and thereby permits accurate estimation of the average signal value through subtraction (biasing)

at the output, or subsequently, in the data accumulation and analysis processes. A discussion of the average and the peak detection processes using sampling concepts appears in the Appendix entitled "Threshold Measurements" and demonstrates that, conceptually, the average detector can provide an accurate estimator independent of the internal noise level of the receiver.

Another potential use of an averaging detector, used in conjunction with a peak detector, can be the determination of excitation's time domain characteristics. If, for example, alternate measurements were accomplished using peak and averaging detectors, the comparison of levels could yield a basis for determining if the excitation were from a pulsed, CW or spread spectrum source, without altering the "no intelligence recovery" ground rule of the experiment. Two considerations are likely to detract from the value of such a scheme in the demonstration receiver, but it was not feasible to model the entire scheme and the various excitation processes (under this project), so its performance is merely deduced here. The narrow bandwidth of the IF channel, and the ambiguity of the peak detector output near threshold are limiting factors to using the two detectors in conjunction for time domain evaluation of interference. The 20 kHz IF passband of each measurement channel imposes a serious limitation on impulse response of the channel, particularly in light of the fact that the receiver will operate with measurement

periods on the order of 400 μsec maximum. The value of measurement comparison evaluations near the receiver's detection threshold will depend entirely on the precision of measurements from the peak detector, already estimated to be poor.

# 11. LESSER ISSUES

## 11.1 General

Consideration of the data extrapolation, resolution, frequency coverage, data volume and minimum discernable signal requirements of the experiment, together with other major study items addressed in the first phase of the project led to the establishment of the experiment's major objectives and to its overall definition. Numerous problems and areas of concern to the establishment and creation of an actual experiment were not similarly addressed however, and some of these which were to some extent considered during the course of the project are discussed in this section of the report. It is important to note that these "lesser issues" are no less important to the success of an overall experiment than any other of the problem areas concerned with the experiment more thoroughly addressed by the project; they are rather lesser issues from the standpoint of determining the feasibility of such an experiment and they do not require detailed investigation or thorough and definitive specifications to prove such feasibility. Indeed, some of these so-called lesser issues are in fact the major element of the "flown" experiment in terms of time and budgetary requirements.

## 11.2 Launch Vehicle and Spacecraft Platform

Primary among the lesser issues with respect to the AAFE man-made noise experiment study which do in fact constitute major issues with respect to the flown experiment is the selection and

implementation of the experiment hardware on a spacecraft and its associated launch vehicle; these selections in connection with the selection and planning of the launch and readiness phases of the flight constitute the largest single outlay on most scientific satellite experiments.

Although experiment cost was a major consideration in the development of the experiment, the use of a dedicated, or experiment unique, platform or space vehicle was chosen. The basis for this selection was consideration of pertinent characteristics of known past and present scientific satellite programs carried out by the United States and allied nations. The weight and power requirements of the receiver for the man-made noise experiment are small enough that, by imposing some constraints on the other experiments of a "hitchhiker" satellite, integration aboard a large satellite of the multi-experiment type would be feasible; most of the NASA scientific satellite projects, however, require orbits which are not feasible for the man-made noise experiment. The majority of NASA spacecraft are launced into either the geostationary or the sun-synchronous orbits. Neither of these has the characteristics necessary for achievement of the primary objectives of the man-made noise experiment; namely the generation of power flux density maps which are time independent and can resolve areas of 100 km or less. The geostationary orbit would reduce resolution of experiment data (in addition to effectively desensitizing the experiment without the use of special high gain antennas or without severe restraint in frequency coverage). The sun-synchronous orbit would prevent the time

independence of data collection on a daily basis from a portion of the earth (i.e., the data taken over any given point on the earth's surface would correspond to a particular time of day). The use of smaller in being or planned platforms for "hitchhiker" orbiting of the man-made noise experiments was deemed impractical because of the power and weight burden which would be imposed by the man-made noise experiment.

One possibility for a small dedicated satellite would be the small applications technology satellite previously known as SATS. During the course of the man-made noise experiment project, the SATS program and its viability waxed and waned to considerable degrees, and at the conclusion of the project its ultimate existence remained somewhat doubtful. If the platform of this type were to be used for the man-made noise experiment, as presently designed, the inclusion of onboard "backside" data collection and post-collection outputting would be prevented by weight constraints. Also, power imposes a severe constraint on the experiment hardware; the feasibility hardware development of the project required over 70 Watts and it is unlikely that, with the similar types of tuned devices as used, this requirement could be reduced by more than 50%. The estimated power available on the SATS for experiment purposes varied from a maximum 30 Watts at optimum sun angles to 20 Watts for non-optimum sun angles (i.e., orbits of greater than 45° inclination).

The selection of the launch vehicle for the experiment will have great impact on its overall cost. The Scout vehicle, which can be launched from Wallops Island or from San Marcos near the Equator is far less expensive in its most uprated standard configuration than the next larger vehicle in the Delta class. The nominal ratio of cost to launch with the Delta as with the Scout vehicles is considerably greater than 2:1. It appears likely that uprated Scout versions will become available with high energy fuels which may close the currently existing cost and performance gap between the two vehicle classes. Some additional information concerning launch vehicle and orbit considerations for the man-made noise experiment are provided in the Appendix entitled Launch and Orbit.

Of course, the fundamental operating parameters of the man-made noise experiment are all amenable to modification over wide ranges without complete loss of the objectives of the experiment; the placement of the experiment package on a wide variety of spacecraft, launched by a Scout or larger vehicle would be entirely feasible for any of the wide range of earth orbits, but within the constraints of the experiment outlined under this project, a dedicated platform on a Delta class launch vehicle probably would be optimum to achieve the necessary orbit characteristics, power availability, etc.

## 11.3 Experiment Duration

The minimum duration for which an experiment such as the AAFE man-made noise experiment would be planned would depend upon the minimum period necessary to achieve the major experiment objectives. In the case of this experiment, the minimum feasible duration would be that which permits the development of power flux density maps over the North American continent and provides otherwise statistically significant data concerning the levels of man-made noise existing at the orbit altitudes of the experiment. The maximum duration of such an experiment will be determined by either the failure of its spaceborne hardware or the cessation of activity in connection with it on the ground.

The period of the orbit specified for this experiment is approximately 105 minutes. The ascending node for each successive orbit of the man-made noise experiment orbit occurs at a point on the equator approximately 26° West of that produced by the preceding orbit. The primary mode of operation of the experiment calls for the use of "full field of view" antennas; the field of view encompassed by the satellite at its mean orbit altitude of 1000 km is approximately 60° (at perigee approximately 50.2°) so that during each successive orbit a considerable portion of the area "viewed" by the preceding orbit will be again within the field of view. "Full area coverage" on any defined area of the earth will require only the number of successive orbits necessary to permit the satellite to pass over that entire area. This is not to say that such coverage will be adequate for any or all

specific objectives of the experiment but it does provide a useful indicator of the orbit's characteristics and "flexibility" in terms of data collection. This type of "full area of coverage" would be obtained for almost the entire earth within a single 24-hour period. For any specified resolution distance at the equator, within a period of time, the satellite track will repeat to within that distance. Determination of the precise period of time required for track repetition to a specific resolution or equatorial distance requires consideration of high order perturbations; a general approximation of this relationship is given in the Appendix entitled Data Handling. From the pertinent figure in that Appendix it may be seen that the period required for approximately 100 km East-West resolution at the equator between successive tracks is on the order of 10 days. (It is important to note that this repeat distance is distance on the surface of the earth rather than distance projected to the satellite orbit's sphere). Resolution along the track of the orbit will be dependent upon the dispersion or frequency band of coverage and the down-link data rate. For example, if the dispersion is 10 MHz and the down-link data rate is 70 kilobits per second, providing a 200 MHz per second effective sweep rate, and assuming a receiver reset time on the order of the period required for the entire 10 MHz sweep, the distance travelled between successive data samples at the same frequency will be less than 400 meters. (This distance is the distance at the orbit's sphere; projected to the earth's surface this results in approximately 330 meter travel distance). Hence it can be seen that resolution along the

track of the satellite does not impose a severe temporal constraint (for "reasonable" dispersions; if the entire 12 GHz spectrum were used as the dispersion for operational data collection, the period between successive samples at the same 20 kHz reference frequencies is on the order of 450 km). Within 1 year in orbit, extensive data could be taken for large portions of the earth for a number of frequency bands of interest, and it appears that a one year minimum duration would be a feasible requirement or expectation for an experiment such as this type.

It is felt that the value of data from experiments such as this would extend over as long a period as such data were made available; the maximum duration for such an experiment, then, unless inhibited by the cost of maintaining ground station support and data processing facilities were limiting factors, should be determined by the ultimate time to failure of the hardware in orbit.

## 11.4 Calibration

A consideration of great import for an experiment such as this is the ability to provide and maintain calibration on the actual measurement hardware to assure that output data will not become erroneous and lead to false conclusions or results. To this end, a calibration device has been included as a component of the spaceborne receiver, and a number of sources of "ground truth data" have been considered and identified for the project.

The calibration device included in the feasibility hardware for the experiment consists of an excess noise generator which provides a flat output of gaussian noise throughout the spectrum of the experiment. Under command, the receiver input may be switched to the noise source and the noise source may be turned on, or turned off, providing a "noise floor" and a gain value for all frequencies included in the dispersion of the experiment.

The ground truth data collection process will entail the comparison of levels obtained from specified orbit positions with those predicted on the basis of known terrestrial emitters in bands which have a very well defined and low occupancy. The use of such ground truth sources for checking experiement performance will provide the desirable tests not only of the receiver and gain/demodulation functions but also will include the antennas and interconnection circuitry in the test.

## 11.5 Up-link Commands

The format for commands to the experiment receiver were specified with respect to the input of the receiver controller. Command carrier frequencies, up-link data rates, commutation requirements, and numerous other aspects of the satellite command process were unspecified and, essentially, unstudied during the course of the project. Considerable flexibility and capability is known to exist throughout the network of NASA ground stations which can be expected to support an experiment of this nature. Command word length required for the receiver's operation is

56 bits in length, exclusive of receiver address. Complements, parity, and other redundancy are not included for the feasibility hardware connected with the project although they would be required for an operational experiment. Because the receiver is capable of operating over extended periods on stored commands, the up-link data rate (or the rate into the receiver controller) is in no way critical with respect to experiment success.

### 11.6 Down-link Data

The primary output of the experiment hardware consists of a data stream whose bit rate is determined by the external interface for the data stream. This dependence is included to assure synchrony with the commutation or other synchronizing requirements of the telemetry interface. The man-made noise experiment did not seek to define this interface or to specify down-link transmission schemes in general. However, it was assumed that, with the built in flexibility of the experiment hardware, the interface and down-link transmission of output data would not constitute a problem of great magnitude. The unified S-band system for telemetry was considered to be typical of those which might be used for data from this experiment; the maximum real time output data rate of the experiment will be equal to 70 kilobits per second. (The high speed down-link telemetry link of the USB system is 51.2 kilobits per second). The data stream provided to the output by the experiment receiver's internal telemetry interface subsystem included individual data points, flags, command sequences, check frequencies, and operational status

information in a non-redundant, non-parity, non-complemented serial bit stream. It is intended that this bit stream be reconstructed at the ground station for initial processing and recording. The byte structure of the data stream is 7 bits. It is likely that the data output of the experiment receiver telemetry interface subsystem will be simultaneously transmitted with the output of a "backside" recorder. The command structure of the experiment receiver controller includes the necessary bits for control of such recorder. The backside recording process and format was not specified, but it seems feasible that the data stream from the experiment receiver be recorded together with a time of acquisition signal. This signal could be provided by the receiver controller which uses a 1000 second interval timer for experiment command updating. During playback, the down-link data stream or streams would consist of the real time data from the receiver and the "backside" data from the recorder, and the latter data stream would be output at a higher rate to include the "clock flag" signal. During the course of experiment design, a dedicated down-link transmitter was postulated for the telemetry channels directly associated with the experiment. Based on the use of 30 foot diameter antennas at the participating ground stations, the use of a 1 Watt transmitter and standard, non-directional antennas on the spacecraft, appear feasible for the down-link data requirements.

## 11.7 Ground Station Equipment

The amount of dedicated hardware required at the STDN participating ground stations for experiments such as this depend upon data and command formats and processing requirements and up-link/down-link frequencies and characteristics. It is anticipated that initial data processing will be performed by the ground station, and it appears likely that a dedicated computer (of the "mini" class) would be desirable for such a project. The primary functions of the ground station data processing equipment and software will be to provide the detection of flags, the inhibition of superfluous or redundant status information, the formatting of the primary data tapes, and the execution of data compression routines as required for reduction in the frequency or spatial domains.

It is not anticipated that resolving capabilities of experi- data collection hardware will be used for maximum resolution in all dimensions. For example, it is unlikely that 20 kHz resolution will be needed for most investigations and missions performed under the experiment. Therefore, ground station processing equipment must be able to generate a single value from a large number of input data points to create a "wideband" data point representing a peak or average value (as appropriate) of the data points so lumped. Programs appropriate for the specific requirements of the data compression in connection with the experiment will be provided in advance to the participating ground stations and will

be entered prior to each data collection pass. The Appendix entitled "Data Handling" provides a number of additional thoughts on the requirements for dedicated equipment at the participating ground stations in connection with the experiment.

## 11.8 Down-link/Up-link Frequency Data Collection

The collection of data at the up-link and down-link freq-quencies associated with the satellite which is used for this experiment may be at some time necessary or desirable. If the experiment includes an onboard data recorder, down-link data collection can be facilitated by operation of the experiment as though it were collecting "backside" data during those periods when it is tuned to the down-link data frequency. It is not anticipated that the up-link command frequency will be used consistently during the course of a pass, and in fact the structure of the receiver and presumably the capability of the satellite will preclude the necessity to up-link commands during every pass, and such capabilities permit the collection of data on the up-link frequency with relative impurity.

Therefore, the only serious problem involved in the collection of data at the operating frequencies of the satellite command and telemetry links consists of the case where the onboard recorder capability is not included in the experiment and the requirement exists for down-link frequency data. The types of antennas anticipated for use in connection with an experiment of this type preclude meaningful interchannel discrimination, and it is unlikely that meaningful data could be obtained from the down-link channel.

## 11.9 Shadow Service

It appears that a satellite of the type postulated for the AAFE man-made noise experiment will be generally unable to collect data during the passage through the night sky. It is highly likely however that such data would be extremely desirable to the experimenter. The period of time during which the satellite will traverse the dark sky will range from 0 to approximately 50 minutes per orbit. It appears unlikely that the receiver on the spacecraft will be able to operate with less requirement than 30 Watts; a 1 Watt output down-link transmitter for experiment data might require a nominal 20 Watts for operation. It is likely then that the shadow service power requirements for the experiment would be at a minimum 50 to 60 Watts for the better part of an hour. It is unlikely that a small satellite using solar cell primary energy input can meet these requirements.

## 11.10 Organization

The organization of a program to support the man-made noise experiment and the institution of necessary channels of communication and liaison and activity interfaces will constitute a task of considerable magnitude. Some rudamentary consideration of the management and organization required for such an experiment is included in the Appendix entitled "Experiment Management". The elapsed time envisioned for the entire project is estimated to be on the order of 4 to 5 years, with a 2 year period required from commencement of the project to the satellite launch date.

Organizational costs for such a project were estimated likely to be on the order of 2.5 million dollars, exclusive of hardware, launch vehicle, and support.

## 12. SIMULATION AND DATA PROCESSING

The man-made noise data collection experiment design was based on the results of an effort to simulate the near earth RFI environment and data collection in that environment under specified operational conditions. The experiment included a data processing concept which was developed to the program stage using the simulation model. Simulation and data processing program development were both accomplished using commercial time sharing services to which NSL subscribes. The programs associated with these efforts are supplied under separate cover as components of the project. The following paragraphs discuss features of these programs and their results and objectives.

### 12.1 Simulation

As part of the initial study to define the man-made noise data collection experiment, a program was written to permit simulation of the RF environment and experiment responses thereto. The simulation, while based on certain unproven assumptions (e.g., cumulative effects of diverse terrestrial emitters), provided means of evaluating alternative measurement antenna configurations. In addition to constructing power flux density maps from interference data received by the satellite borne RFI experiment, the task of determining the interferor's location on the surfaces of the earth falls to the data processing portion of the experiment. Also, because of the extensive frequency range covered by the experiment a large number of different types of interference sources should be visible to the RFI receiver. A detailed

knowledge of the expected power flux density levels and radiation patterns at the satellite orbit generated by known types of interference sources would be invaluable to the design of the entire experiment. The possibility also exists, of using several classes of strongly channelized interference sources as ground truth data for the experiment. For these reasons it was felt, at the beginning of Phase I, that an extremely complete and very flexible qualified simulation program should be written.

In order to construct a complete model of the expected interference at orbital altitudes many factors were considered. They were divided into three major classes:

- o Interference source characteristics;
- o Spacecraft receiver system characteristics;
- o Interference link characteristics.

The interference source characteristics included such factors as transmitted power levels and frequency spectra, antenna types and patterns, antenna pointing azimuths and elevations, and transmitter locations on the earth's surface. The transmitted power level, transmitter location and antenna pointing were generally static parameters, not changing throughout the simulation. However, antenna gains and frequency spectra of the interference were dynamic in nature; they change with time as seen by an orbiting, frequency scanning RFI receiver.

Spacecraft receiving system parameters were all time varying. If the receiver was scanning, its center frequency was time varying, and since it is moving, its antenna gain in the direction of any given fixed ground point was also time dependent.

Because of the satellite's movement, the interference link was also variable with time. Range was continuously varying, and a doppler component was added to or subtracted from the frequency spectrum of the interference source.

Since the simulation program was initiated in the early portion of Phase I, it was designed to be as flexible as possible in order to test and reflect the various ideas proposed for the overall experiment design. This necessity for flexibility yielded a simulation program which handles up to 10 interference sources simultaneously. Each interference source may be characterized by any of three frequency spectra (television; narrowband line-of sight, or wideband line-of-sight) and one of 16 different antenna patterns, pointing at any azimuth or elevation and located anywhere on the earth's surface. The spacecraft receiving system may be characterized by any one of 16 different antenna patterns pointing in any direction with respect to the spacecraft's coordinate system, coupled to a stepping, sweeping or fixed bandwidth receiver whose step rate and bandwidths may be set at any desirable values and is carried abroad a satellite flying any circular orbit.

The simulation can begin and proceed in a number of ways, depending on the particular type of data required of a particular simulation run. For example, it is possible to begin the simulation with the spacecraft located above a given point on the earth's surface ascending, or descending along its orbital path and recording data as functions of time, frequency, or satellite position.

The program is also capable of having a satellite positioned at a given point and backing the satellite up along its orbital path until all the interferors disappear below the satellite's horizon. This option ensures that a complete path of a set of interferors will be made.

In considering the experiment data processing requirements, it was realized that data processing will take two forms. Initial processing will be, in essence, a reformatting of the received RFI data. The reformatting will convert the received data from that taken along an orbital track into power flux density contour maps. The second phase of data processing may deal with determination of the locations of interferors on the earth's surface or extrapolation of the data to other orbital altitudes. In order to supply simulation inputs to these two phases of data processing, the simulation program was constructed so that both orbital interference data and power flux contour maps could be generated. The orbital interference data will simulate the output data tapes from NASA ground stations including interference data, identification blocks and timing information. Power flux density maps produced by the simulation program can be used to check the output of the data processing package and can also be used as an input to the second stage data processing package. Examples of both types of simulation output are shown in Figures 12-1 and 12-2.

The simulation results brought to light several factors which were extremely important in the design of the experiment. In particular, the effects of high gain, narrow beam antennas produced

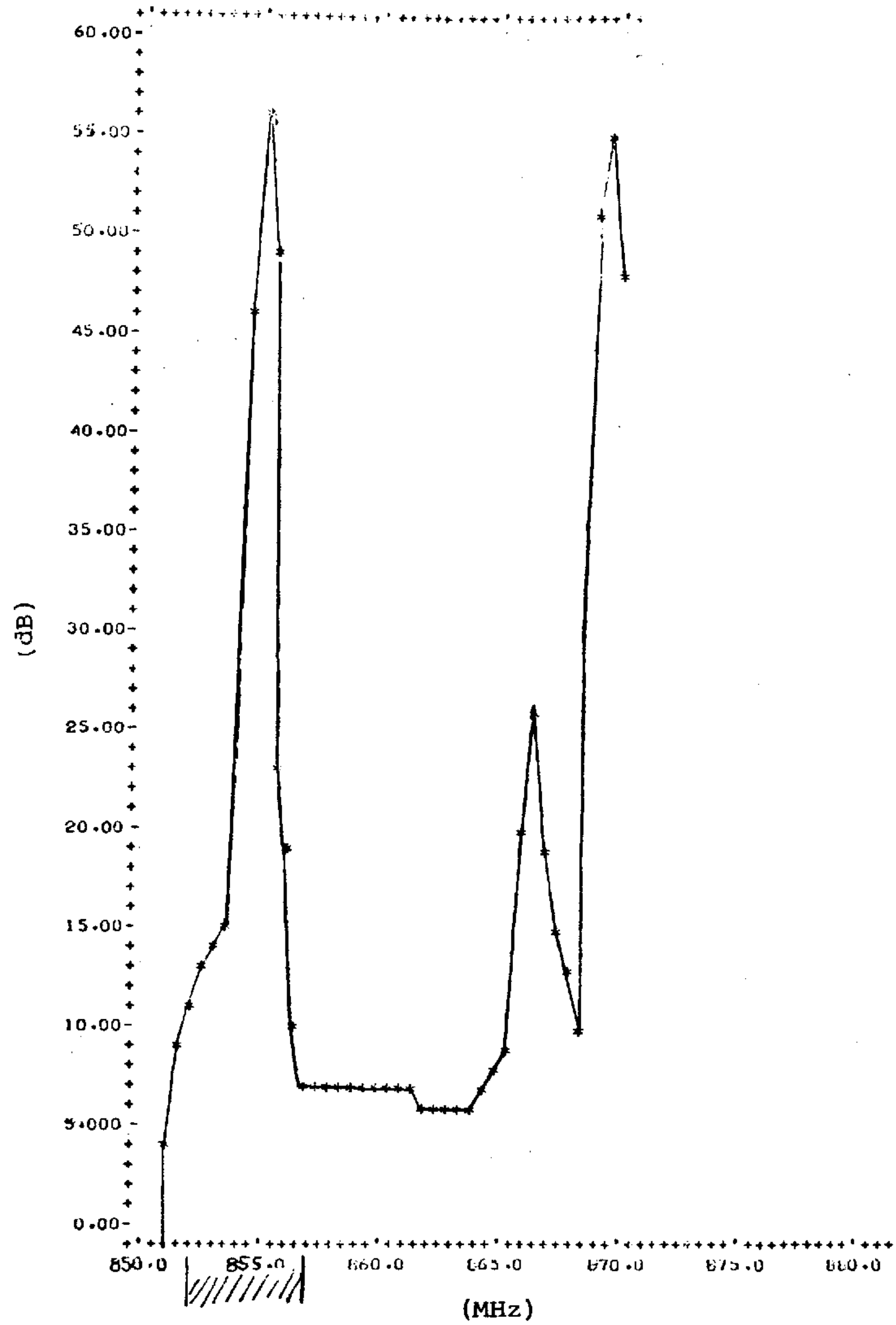



FIGURE 12-1 SAMPLE SIMULATION: RECEIVED PFD VS. FREQUENCY

```
PØSTIØN PAPER THEN (CR)
       +'+++++++++'+++++++++'+++++++++'+++++++++'+++++++++'+++-
 63.00-
       +
       +1111111111111111111111111111122222222222222211111
       +1111111111111111111111112222222222222222222222111
       +2222221111111111111111222222222222222222222222222
 58.00-2222222222221111111222222222222222222222222222222
       +2222222222222222122222222222222222222222222222222
       +2222222222222222333322222222223333333333333332222
       +2222222222222223333333222222233333333333333322222
       +2222222222222222233333333222233333333333333333333
       +2222222222222222233333333344422233333233333333333
       +3322222222222222223333333334444333333332222233333
       +3332222222222222223333333344444443333332222220002
 50.00-2222222222222222233333333344444333000000000000000
       +2232222222222222223333332222333333333000000000000
       +3332222222222222223332222222222332222220000000000
       +3322222222222222211122222222222222222220000000000
       +3222222222222211111122222222222222222221100000000
 45.00-2222222222211111111111122222222222222221110000000
       +2222222211111111111111111122222222222211111110000
       +2222221111111111111111111111111111111111111000000
       +2221111111111111111111111111111111111111100000000
       +0111111111111111111111111111111111111100000000000
 40.00-0111111111111111111111111111111111110000000000000
       +0011111111100000000000001111111111000000000000000
       +0001110000000000000000000000000000000000000000000
       +000000Pp00000000000000000000000000000000000000000
       +0000000000000000000000000000000000000000000000000
 35.00-0000000000000000000000000000000000000000000000000
       +'+++++++++'+++++++++'+++++++++'+++++++++'+++++++++'++++
     70.00     60.00     90.00     100.0     110.0     120.0
```

FIGURE 12-2 SAMPLE SIMULATION: PFD MAP AT 1000 KM ORBIT

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

C-2

surprising results. Figures 12-3 thru 12-8 show an identical simulation model, with the exception of the ground and spacecraft antennas being used. All four figures display received power flux density above an arbitrary minimum detectable signal level, with time as the spacecraft traverses a direct overhead pass on a single ground station. In all three cases the ground station antenna is pointed directly at the point on the horizon at which the satellite initially appears and the spacecraft antenna is pointed at its nadir. In Figure 12-3, the spacecraft antenna is isotropic and the ground station antenna has a sidelobe pattern of the CCIR reference antenna pattern.* The CCIR reference antenna pattern has a very smooth sidelobe decay function. Because of the lack of sidelobes on both antenna patterns, a relatively smooth transition in received power flux density is made from a peak PFD as the satellite passes through the main beam of the ground station antenna to the time when the satellite passes out of sight of the ground station. Figure 12-4 shows a slightly more complex situation in which both the spacecraft and the ground station are using CCIR antenna patterns. In Figure 12-5 a farther complex set of antennas is used. The spacecraft antenna now has the smooth sidelobe CCIR reference antenna pattern while the ground station has a simulated parabolic aperture antenna pattern (SinX/X distribution). As can be seen in Figure 12-5 a pronounced lobing effect occurs due to the SinX/X ground station antenna pattern. The maximum power received at the satellite no longer occurs in the main beam of the ground station but occurs during interaction of the spacecraft

*G,dBi = 32 - 25 log Ø, Ø being angle in degrees from the pointing axis of the antenna.

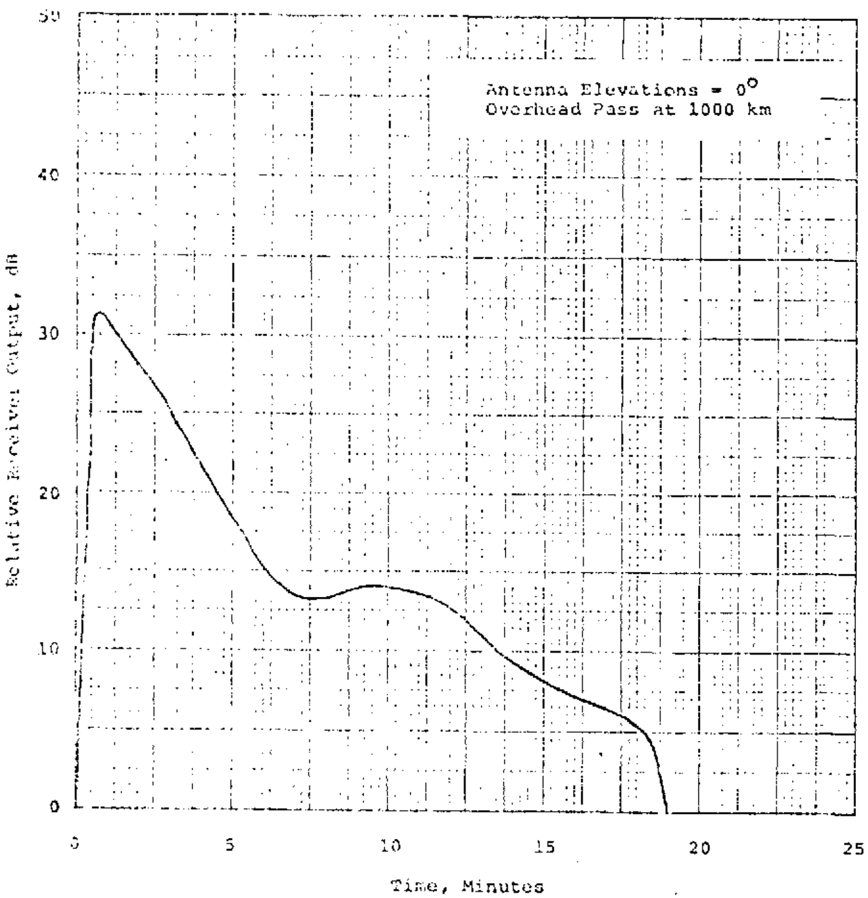



FIGURE 12-3 MODELED RECEIVER RESPONSE FOR ISOTROPIC SPACECRAFT ANTENNA AND CCIR GROUND ANTENNA

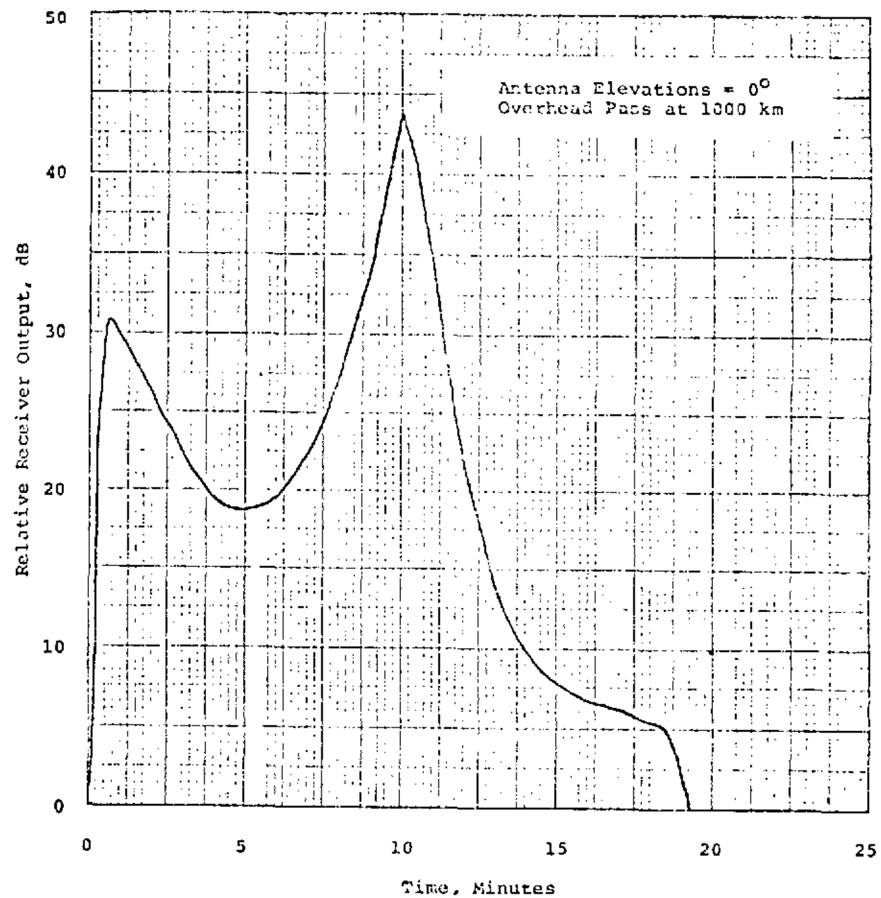



FIGURE 12-4 MODELED RECEIVER RESPONSE FOR CCIR SPACECRAFT ANTENNA AND CCIR GROUND ANTENNA

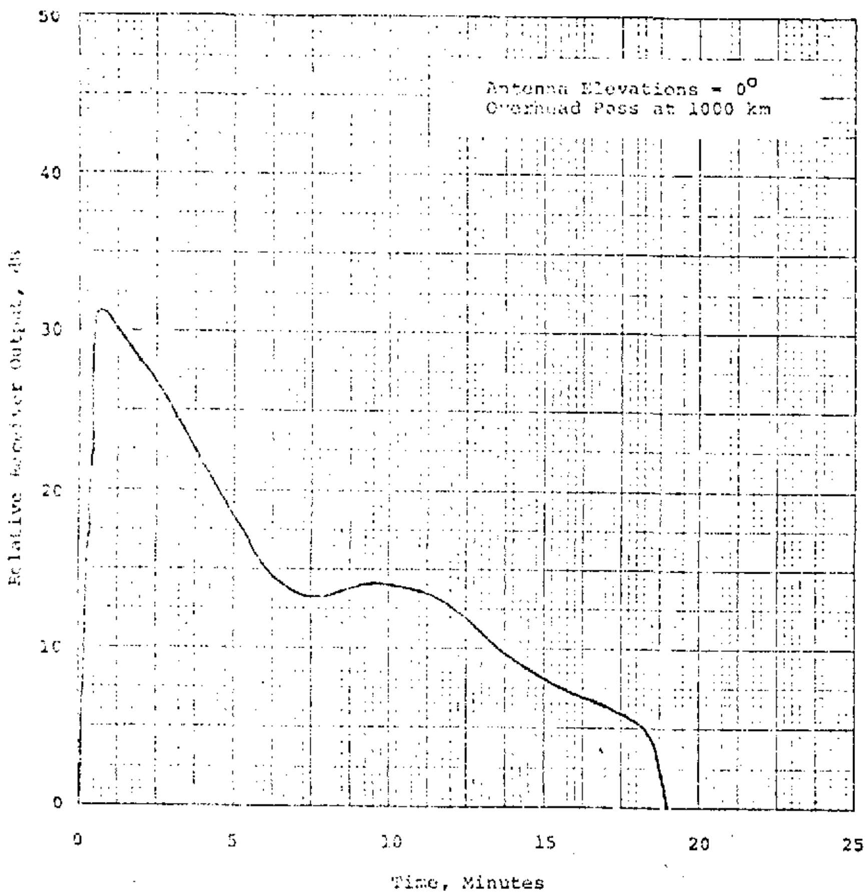



FIGURE 12-5 MODELED RECEIVER RESPONSE FOR CCIR SPACECRAFT ANTENNA AND SIN X/X GROUND ANTENNA

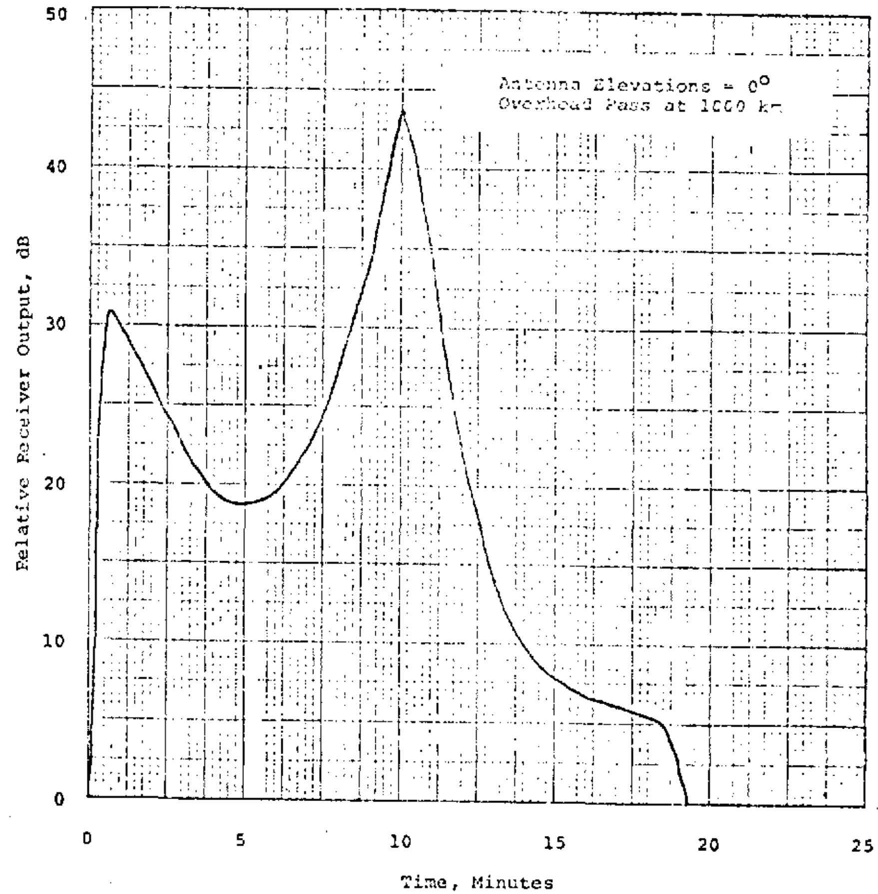



FIGURE 12-6 MODELED RECEIVER RESPONSE FOR SIN X/X SPACECRAFT ANTENNA AND SIN X/X GROUND ANTENNA

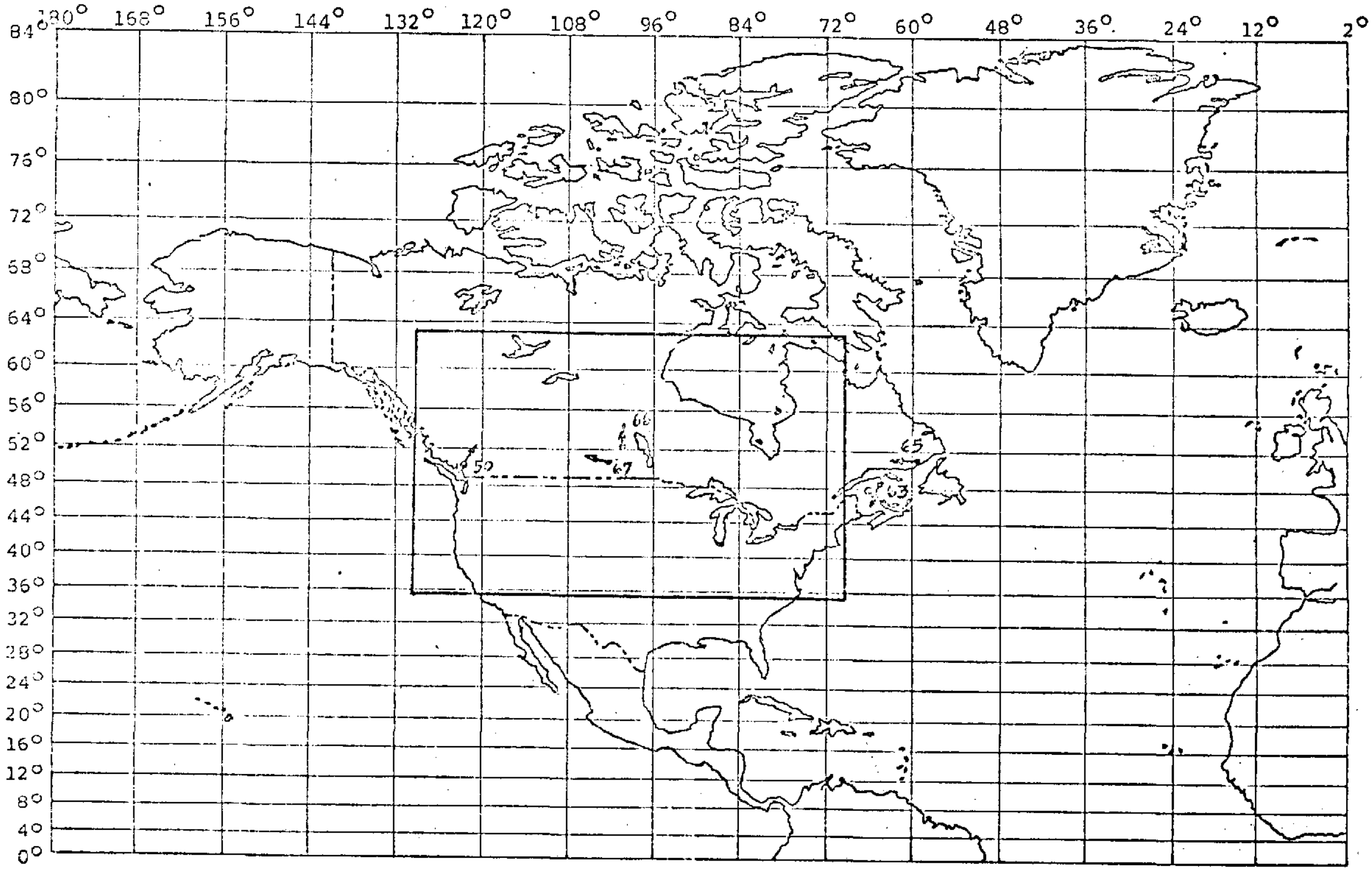
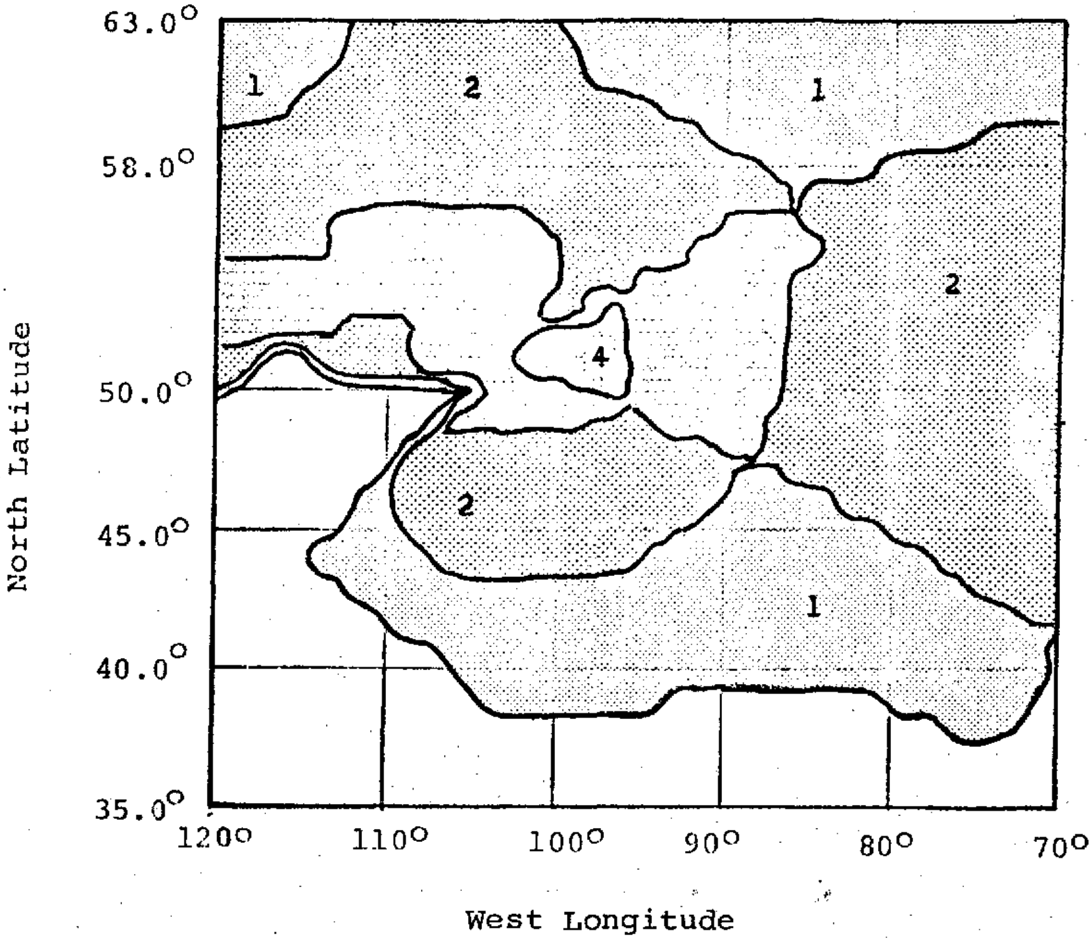



FIGURE 12-7 GROUND STATIONS AND AREA MAPPED IN SIMULATION

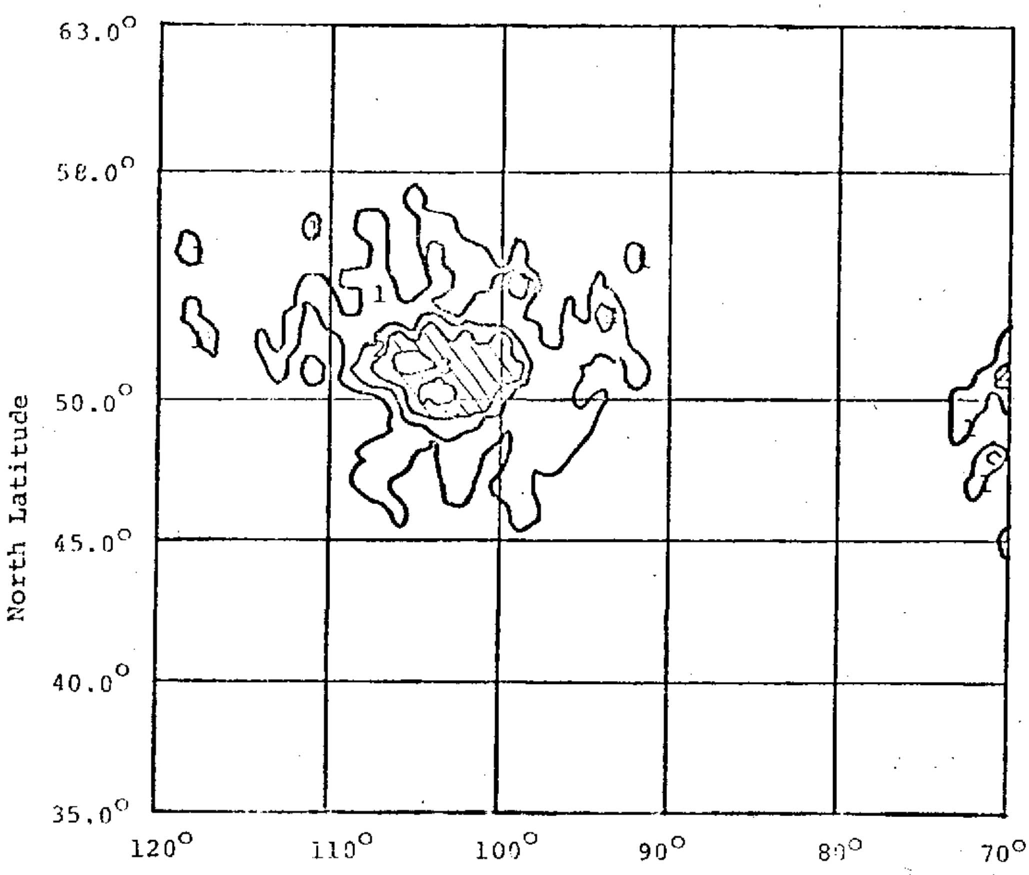



S/C PARAMETERS:

MDS: -140 dBW
Antenna: 5 dB - Full Earth Coverage
Frequency: 2067-2067.2 MHz
Orbit: 1000 km, 63.5 deg. inclination
Ground Stations No. 50,63,65,66,67
Each Contour = 2 dB

FIGURE 12-8 SIMULATED PFD MAP AT 1000 KM ORBIT, FULL FIELD OF VIEW SPACECRAFT ANTENNA

main beam with a side lobe of the ground station. The model used to produce Figure 12-6 uses as a spacecraft antenna pattern the SinX/X distribution of a parabolic aperture and a ground station antenna pattern of a parabolic aperture. The figure shows a very pronounced lobing effect and a greatly reduced peak in the maximum power flux density seen at the satellite. As opposed to the strong and narrow peaks in Figures 12-3 and 12-4 a relatively flat power flux density level is observed. It must be emphasized that the only difference in these 3 simulations is the type of antenna patterns used onboard the spacecraft and on the ground station. Figures 12-7 and 12-9 again emphasize the different power flux density results obtained when different antenna patterns are used. Figure 12-7 is a map of the North American continent showing five line-of-sight stations which belong to the Canadian 2.075 GHz micro-wave communication network. These 5 stations were used to generate simulated power flux density maps obtained at a 1000 kilometer orbit. The two PFD maps shown in Figure 12-8 and 12-9 were made with identical simulation models again with the exception of the spacecraft antenna patterns used. Figure 12-8 uses a 5 dB gain full earth coverage antenna and the contours produced in the simulated power flux density map very definitely show the expected contour shapes. A directive emitter on the earth's surface will generate a cone of energy which will intercept an orbital sphere with tear drop shaped contours. These again are very easy to distinguish in Figure 12-8. It is even possible in the figure to determine, from the shape of the contours the line along which the emitter must lie and in fact even the direction that the emitter must lie in. Figure 12-9 was made using a SinX/X antenna




S/C PARAMETERS

MDS: -140 dBW
Antenna: 2m - $(\sin X/X)^2$
Frequency: 2067-2067.2 MHz
Orbit: 1000 km, 63.5 deg. inclination
Ground Stations No. 50,63,65,66,67
Each Contour = 2 dB

FIGURE 12-9 SIMULATED PFD MAP AT 10-0 KM ORBIT,
HIGH GAIN SPACECRAFT ANTENNA

pattern on the spacecraft simulating a 2 meter antenna operating at approximately 2 GHz. The resulting power flux density maps shows no contour detail and in fact a definite loss of information has occurred due to the lobing on the parabolic antenna.

This loss of information due to the angular weighting of the received data by the receiving antenna is one of the major reasons for the recommendation of wide beam antennas. While the narrow beam antennas can yield higher gains in the pointing direction, the RFI receiver will be in the position of having signals beamed at it over an almost complete hemisphere. Hence, any signal coming in outside of the main beam will be modified by the side lobe characteristics of the receiving antenna. The amount of modification will be dependent on the precise angle at which the interference is received. The side lobe patterns of narrowbeam antennas are exceedingly complex and vary extensively with angle off main beam. To complicate matters further, the great majority of the usable spectrum is allocated to the fixed point-to-point service, which uses highly directive horizontal beams. The result is that they will be "seen" best at an angle of approximately 70 degrees up from the nadir at an orbit of 1000 kilometers. If the satellite uses a narrowbeam antenna pointed vertically downward, it will encounter the main beam of the fixed service transmitters approximately 70 degrees off the satellite antennas main beam, and while passing directly over a transmitting fixed service installation the spacecraft receiver will be seeing the ground antenna approximately 90 degrees off its main beam. In between these two cases the response of the RFI receiver will be determined by the side

lobe patterns of both the ground station and the satellite antenna. As a result, data taken through a narrowbeam satellite antenna will be severely modified and distorted, decreasing the utility of the data considerably. A power flux density map produced from this type of data would be characteristic only of a satellite flown with that particular antenna at that particular altitude. The problem of extrapolating interference data to other orbital altitudes, in this case, is akin to viewing an object through colored glasses of an unknown color and later attempting to determine its true color.

The use of earth encompassing antenna pattern would produce data which is unmodified by the measuring system and would allow the extrapolation of the data not only to other orbits but also to other types of receiving antennas to facilitate future spacecraft designs.

## 12.2 Data Processing

The characteristics of man made noise experiment receiver are such that, in conjunction with ground processing, a wide latitude in the incremental or quantization levels of individual measurement parameters is readily attainable. The recommended limits on attainable measurement characteristics and quantization levels are as follows:

- o Amplitude: peak level during measurement interval; 1 dB increment; 65 dB dynamic range
- o Spatial: dependent on tracking accuracy and records; one measurement interval per 4 meters of spacecraft travel;

- o Frequency: 20 kHz passbands specified to 1 Hz/MHz; five contiguous passbands measured simultaneously per measurement interval;
- o Time: 500 microsecond minimum measurement interval; accuracy dependent on progagation ambiguity and ground station clock quantization accuracy.

Each primary data point will describe the peak level of incident RF energy in one of five simultaneously measured contiguous 20 kHz channels during a 500 microsecond measurement period and a 4 meter track segment of the satellite orbit. When constant gain antennas are used, the measurements will not be highly influenced by RF energy incidence angle; when the constant aperture antenna is used, the directivity characteristic will weigh the measurement appreciably.

In operation, the experiment will collect data using the following sequence. When a command is received, the output data stream will convey the command word and then commence outputting data bytes; upon completion of 500 data samples (10 MHz), flag words are outputted identifying 10 MHz crossover points. Upon completion of each full scan, flag words and the command words are inhibited as required during the transmission of non-measurement data to assure that all measurement intervals are of uniform duration.

The procedures and techniques established for the flow, storage and processing of data from the experiment are directed to efficient use of ADP equipment and the magnetic tape storage medium, to timely generation of useful output, and to flexibility in the hands of the principal investigator. Central to the data handling and analysis scheme is the concept of a central, fixed size magnetic tape library for archive storage of reduced data. Such a library will contain the accumulated statistics on levels encountered in addressable records identified by spatial, spectral and temporal characteristics, and the statistics will be updated throughout the course of the experiment.

Two objective modes of operation are planned for the experiment. The first mode measures and stores peak power levels as a function of frequency, geographical area, time of day, time of year and satellite altitude in order to develop power flux density maps that depict the levels of interference in terms of the above parameters. The second objective mode measures interference levels in narrow frequency bands, over relatively small geographical areas, at specific diurnal or annual phases, on a demand basis. The basic processing algorithms and data reduction procedures will be similar for both modes. The primary difference will be in the dimensional resolutions or boundaries to be used in the data storage library.

Within such a library, the lowest individually addressable element is a frequency record. The frequency record contains a number of amplitude cells, a maximum and a minimum amplitude byte, and a flag. The amplitude cells each contain the count of samples falling within their amplitude boundaries. The amplitude bytes

provide the highest and lowest levels encountered within the record, specified to the precision of the original data. The flag is set if any of the amplitude cell counts exceeds the maximum for that cell; no further data is accepted for a record with a flag. The frequency record is bounded in time, and space by a location or address hierarchy which facilitates its acquisition and use.

A practical library organization provides for the storage, retrieval and updating of archive data with a minimum number of sequential storage area passes. A typical library could store by annual season, nominal altitude, geographic resolution element, diurnal phase, and frequency. Data will be classified initially by annual season of acquisition (one of four). It will then be specified as to acquisition altitude (either apogee or perigee); the orbit has been specified to facilitate this classification. The geographic resolution element provides the next descriptor, and finally the acquisition frequency identifies the location of the data to be manipulated. Hence, in a typical library, each of four seasonal sublibraries will contain two altitude sectors. Each altitude sector will contain a number of geographic "bins", and each "geo-bin", in turn, contains a number of diurnal blocks. Within each diurnal block, a set of frequency records are contained. With the assignment, by the principal investigator, of practical boundaries in each of these dimensions, the incoming data can be buffered, indexed, smoothed and accumulated in the appropriate locations within the operational library.

The orbit for the experiment is eccentric. The ratio of its perigee to apogee is 2.0. The satellite will be within ± 10% of

its apsidal altitudes during approximately half of each orbit, permitting the classification of input data by two distinct orbital spheres. (Such concentric measurements will facilitate the estrapolation of data to other altitudes and to the earth more readily than a single altitude orbit scheme). It is for this reason that the primary data index is by altitude.

The "geo-bin", or geographic resolution element, conceived for the experiment will define an area specified in terms of equatorial longitude boundaries and latitude boundaries. The shape, or form, of each geo-bin will depend upon its latitude boundaries: at or near the equator, geo-bins will closely approximate parellelograms (on a planar map) but near the inclination limit (63.5°), they will appear to have curved boundaries. However, such bins facilitate data indexing and cataloging, and are, in fact, no less "regular" than any other readily defined spherical surface apportionment.

A more detailed treatment of the data processing concepts is given in Appendix D and is included with the detailed computer program documentation.

# 13. FEASIBILITY HARDWARE

## 13.1 Concept and Evolution

At the outset of the AAFE Man-Made Noise Experiment Project, it was intended that frequency coverage of the receiver to be built under project auspices would provide little more than one octave coverage, but would be versatile in providing for a plug-in or otherwise interchangeable front-end assembly to permit selection of the band to be covered. A single front-end assembly was to be provided for conceptual demonstration purposes.

Another original concept for the demonstration receiver was that a VCO local oscillator would (probably) be used for frequency scanning in light of its relative simplicity. The need for consideration of a more accurate and noisefree local oscillator was recognized, but it was generally felt that a VCO would be more feasible on consideration of weight, spurious signal generation, reliability, and power requirements.

Yet another initial concept for the experiment hardware was that commands would be stored in a non-volatile fashion in the receiver's control circuitry [which was identified prior to the project as a "command decoder, sequencer, controller (CDSC)"]. The reception of appropriate command addresses then would set the sequence of stored commands for any operational period.

These initial concepts were soon dispelled, as discussed elsewhere in this report, by a number of original notions. First, the single octave frequency coverage was recognized as being prohibitive for such an experiment. The receiver design team, relying on recent

surveillance technology, designed a new approach using up/down conversion and YIG tuned elements both for preselector filtering and for a controllable local oscillator. A major trade-off related to power consumption at this point. If power were overriding, YIG tuned devices would not suffice since their power consumption relates to their tuned frequency and is appreciable at any frequency of operation. And, YIG tuned devices require oven temperature stabilization, an additional power requirement of notable magnitude. However, upon due consideration it was concluded that performance would take precedence, and the YIG component design was pursued. With a multi-octave frequency range of coverage, the use of preset frequency bands now was felt to be implausible, and a multi-byte command word in conjunction with volatile sequencing memory was adopted to permit ongoing selection of frequency coverage and other experiment elements in any combination. The entire range of operational variables would be specified by each command, which would also include its time of initiation. A sequence of these commands could then be loaded for long term control of the experiment spaceborne segment.

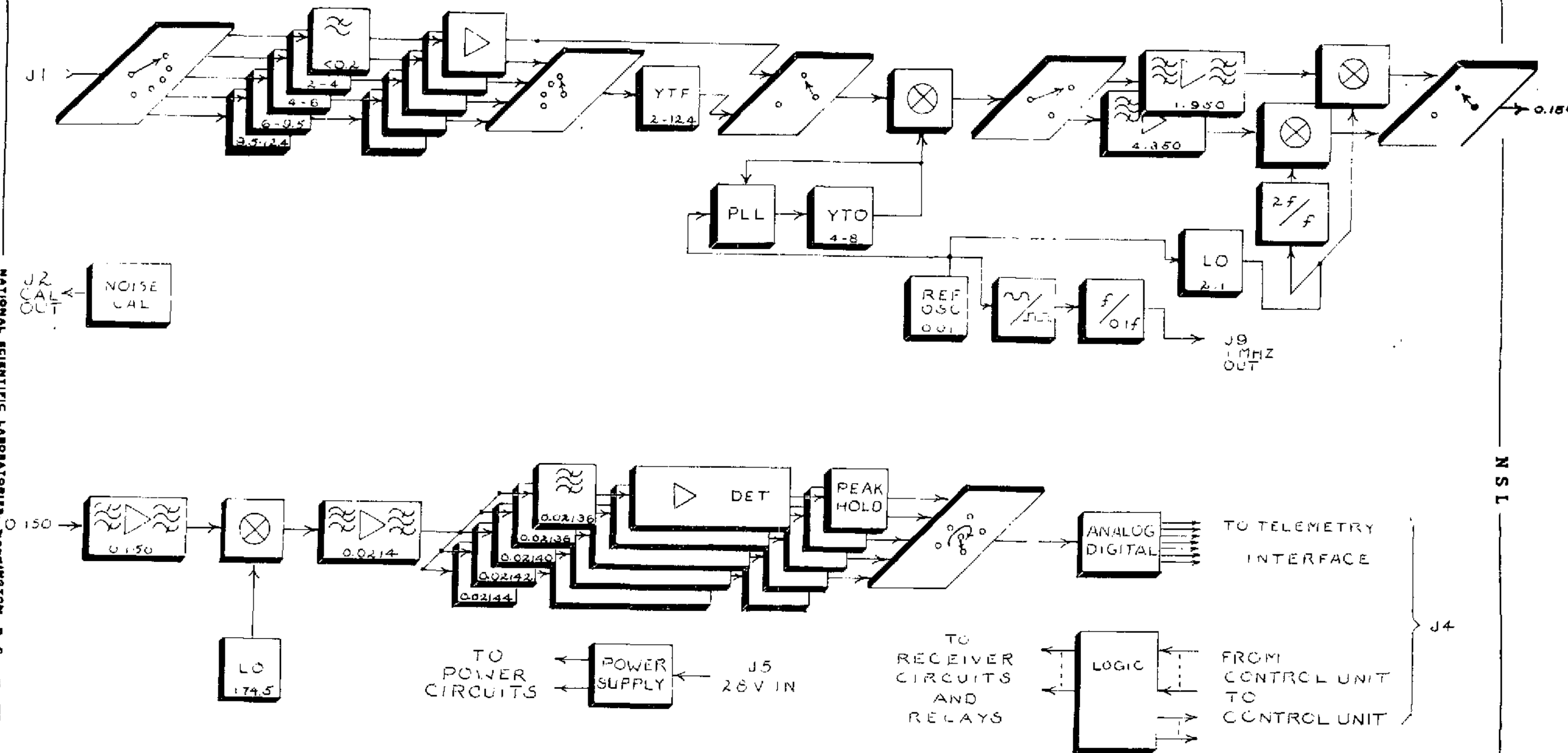
In order to optimize cw sensitivity, the pre-detection passband of the receiver was limited to 20 kHz. In order to facilitate measurement accuracy with respect to frequency, the tunable local oscillator was phase locked to a reference crystal oscillator (providing a synthesized output) and incremented to provide scanning. The maximum effective scan rate of the receiver was found to be unduly inhibited by the necessary dwell, or sampling, interval which could be achieved with such narrow passband. The

response time of the band limiting IF stages, the reset interval required for those stages, and the incrementing interval of the synthesized local oscillator appeared to limit the maximum scan rate to less than 100 MHz per second. This inhibition was overcome by the provision of five parallel-connected final IF/detector circuits, with contiguous, 20 kHz passbands, providing a 100 kHz frequency coverage during each sampling interval through the use of five 20 kHz channels. The fundamental tuning increment of the receiver was now 100 kHz, and the sampling interval could be increased by a factor of 5 for a given scan rate. The maximum scan rate of 200 MHz per second was readily attained with this technique, although the predetection passband of the receiver for each measurement was 20 kHz.

## 13.2 The Demonstration Receiver

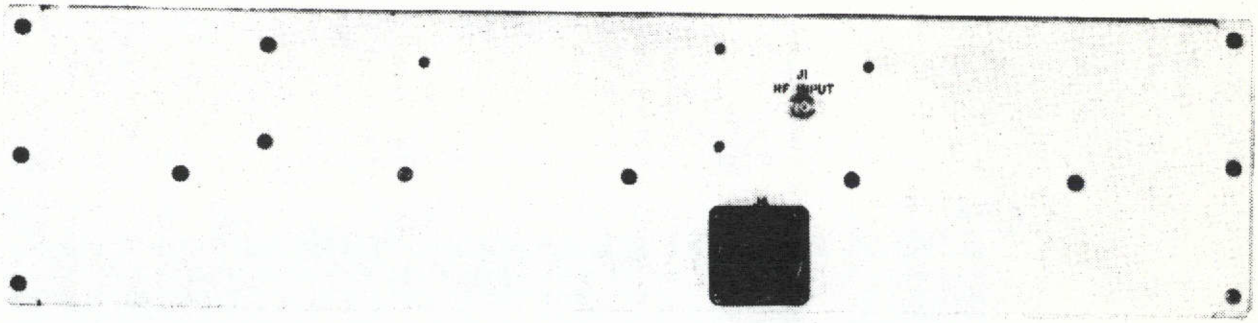
Figure 13-1 is a functional block diagram of the demonstration receiver. All functions shown are housed in a single box of approximately 43 cm x 43 cm x 11 cm dimensions. Figures 13-2, 13-3 and 13-4 are pictorial representations of the demonstration receiver in various altitudes. This receiver was designed and fabricated by the Watkins Johnson Company, Gaithersburg, Maryland.

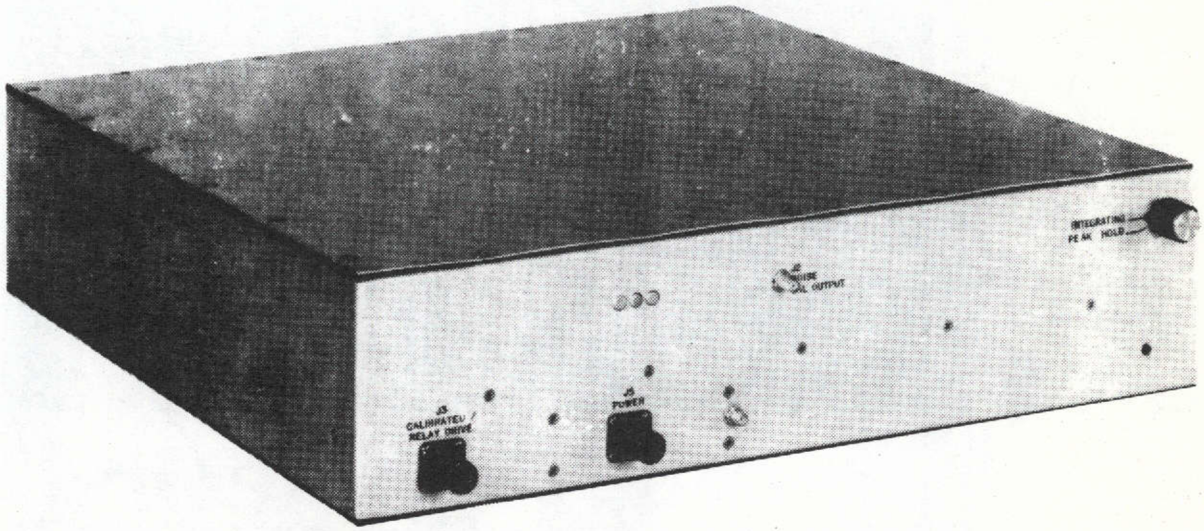
The receiver is a triple conversion superheterodyne type employing five internal bands with up/down conversion techniques used for the lower bands. Its control is digital (excepting a detector function selector which is manual), and all outputs with the exception of a reference noise calibrator are digital. The manual detector function selector was added at a late stage of




NOTE: NUMBERS REFER TO OPERATING FREQUENCY, GIGAHERTZ

FIGURE 13-1 AAFE MAN-MADE NOISE EXPERIMENT RECEIVER FUNCTIONAL BLOCK DIAGRAM



APPROXIMATE CASE DIMENSIONS: 43cm X 43cm X 11cm

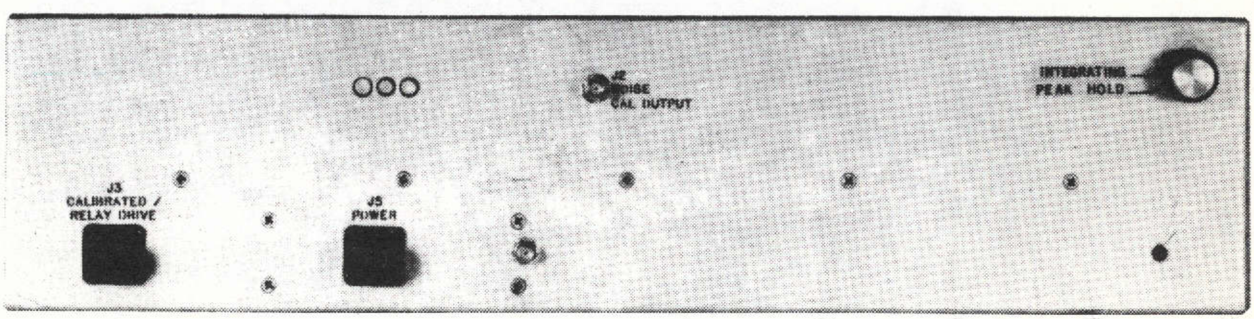



FIGURE 13-2 AAFE MAN-MADE NOISE EXPERIMENT DEMONSTRATION RECEIVER

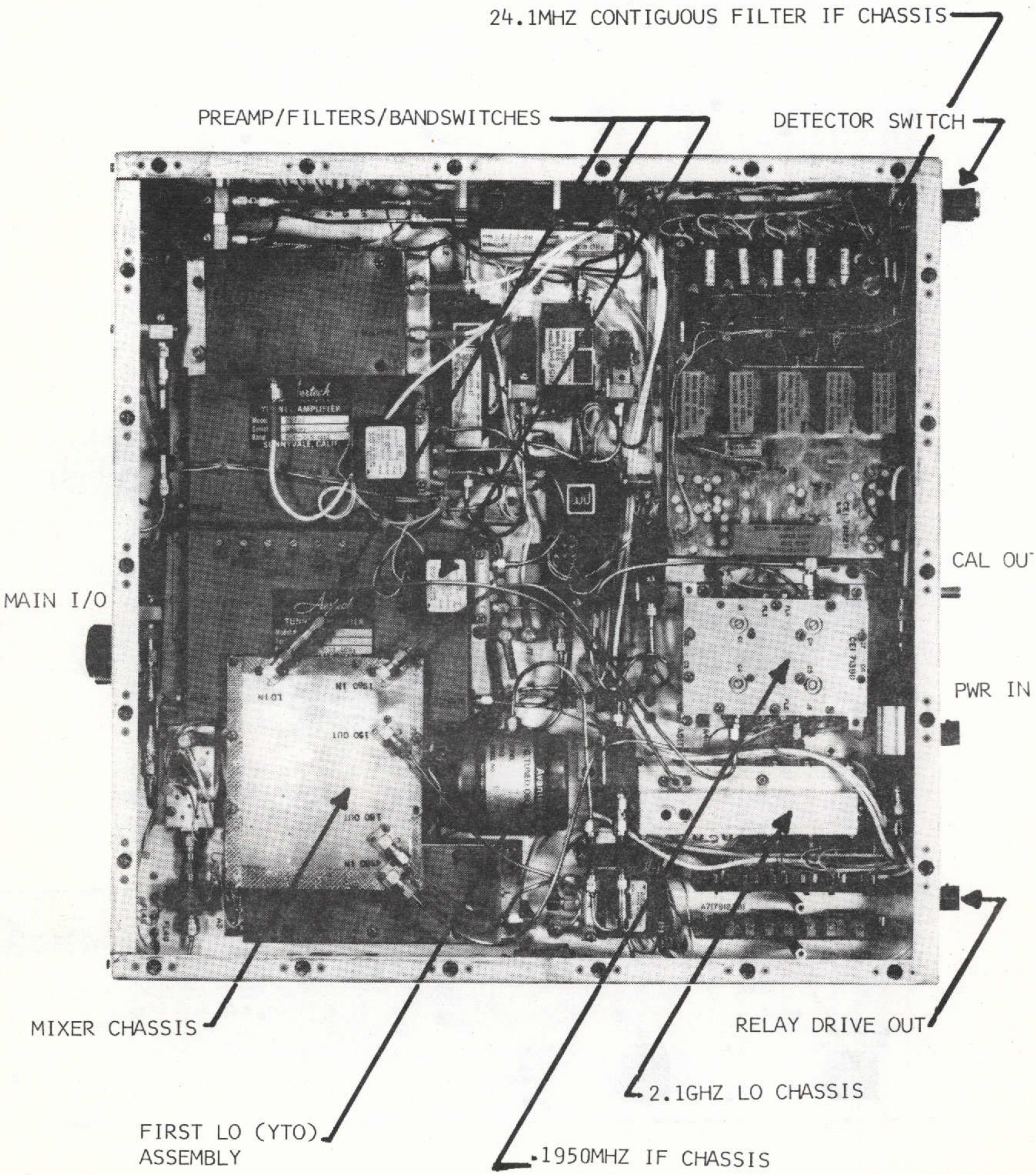



FIGURE 13-3 AAFE MAN-MADE NOISE EXPERIMENT DEMONSTRATION RECEIVER: MAIN RF COMPARTMENT

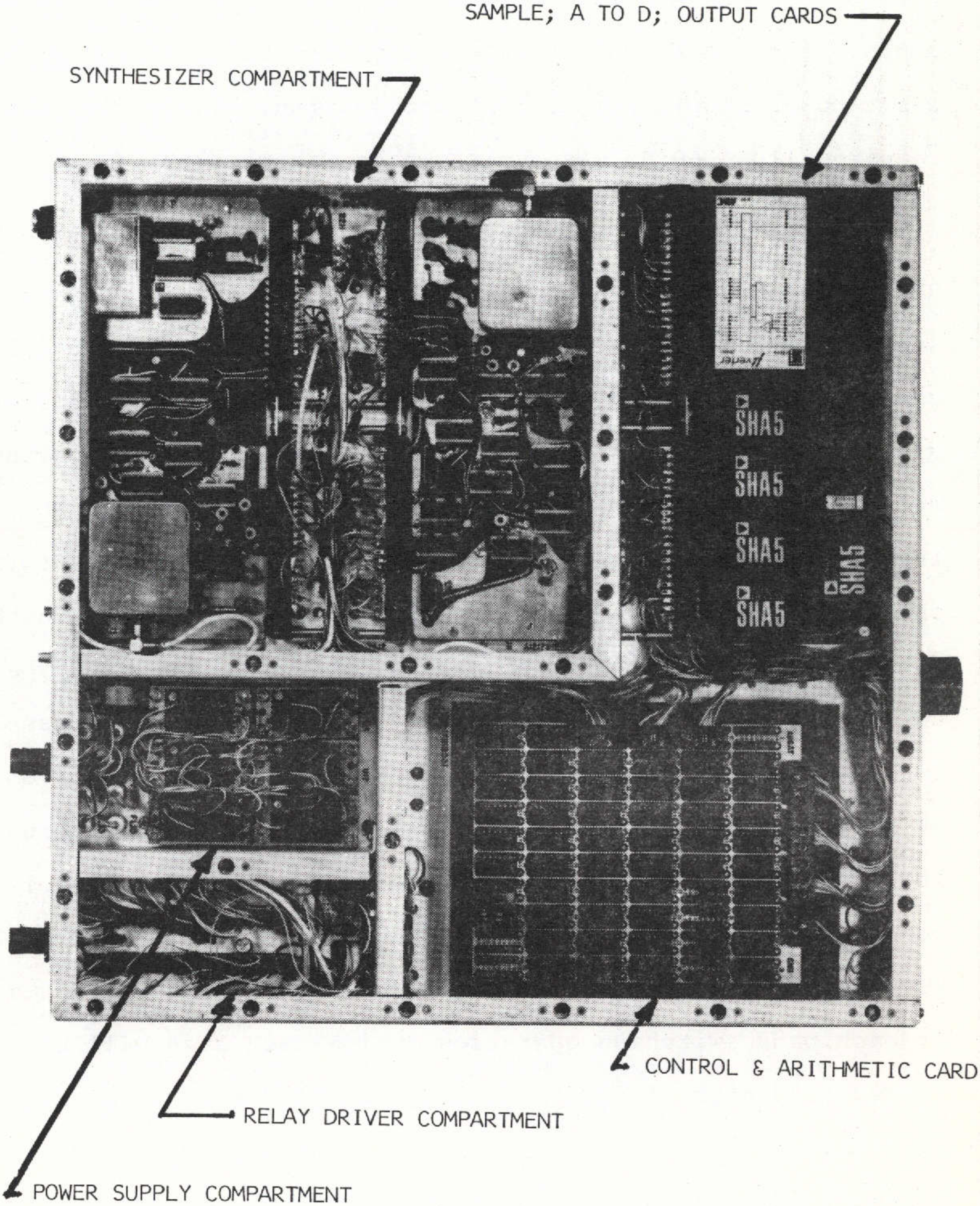



FIGURE 13-4 AAFE MAN-MADE NOISE EXPERIMENT DEMONSTRATION RECEIVER: POWER, DIGITAL AND SYNTHESIZER COMPARTMENTS

development; it provides for either peak- or average-level measurements by the receiver. Another very late addition to this device was a power supply compartment cooling fan. (This fan, which requires 110V, 60 Hz, is not shown in Figure 13-2).

The RF signal input to the receiver is via a single SMA type RF input connector. SMA connectors and semi-rigid coaxial cable are used extensively for RF and IF assembly and component interconnections. The RF input is fed to one of five band filters via a network of single pole double throw relays (indicated as a multi-throw switch on the block diagram, Figure 13-1). The frequency ranges of the five bands are determined by performance characteristics of the five RF preamplifier assemblies which follow the filters. The low band filter is a low-pass type whose cutoff frequency is 2 GHz; the remaining four are bandpass filters for 2 to 4 GHz, 4 to 6 GHz, 6 to 9.5 GHz and 9.5 to 12.4 GHz. RF relay switching throughout the receiver is under internal logic control and is automatic insofar as external control is concerned. If the receiver is commanded to scan a band of frequencies which includes an internal band change, the execution of each band switching operation during each scan will be performed automatically by the receiver, and during each switching interval, an inhibit (LOCK) signal is output. The bandswitching interval required by the receiver is 200 msec nominal.

The RF preamplifier output is fed to the first mixer, which operates over the entire tuning range of the receiver. When the receiver tuned frequency is above 2 GHz, the preamp output is

fed to the mixer via a three stage YIG tuned filter whose bandwidth is approximately 25 MHz, and which is nominally tuned to the center tuned frequency of the receiver during operation from 2 to 12.4 GHz. The first local oscillator is synthesized (phase locked to a crystal reference source) and tunable in 100 kHz increments from 4 to 8 GHz, under receiver logic control. The first IF tuned frequency, relay selected, is either 1950 MHz or 4350 MHz. The second local oscillator is also synthesized and supplies either 2100 MHz or 4200 MHz to the appropriate second mixer, in either case producing a 150 MHz second IF signal. The third local oscillator is a 171.4 MHz crystal controlled source which is mixed with the second IF to produce a 21.4 MHz third IF signal. In the third IF section, which is part of the "IF/video subassembly", as designated by the manufacturer, the passband is initially limited to 100 kHz, after which the signal is fed in parallel to five 20 kHz passband filters providing contiguous band coverage of the 100 kHz passband. Center frequencies of the five filters are 21.36 MHz, 21.38 MHz, 21.40 MHz, 21.42 MHz and 21.44 MHz.

Each 20 kHz filter is followed by a successive detection logarithmic amplifier detector whose output is a log response function of its input envelope level. The output of the detector is fed to a peak hold detector whose output is, is, in turn, amplified to provide the proper signal gain. During the course of the project, an alternate detector function was determined to be required and was added in the form of a switch selected integrator (electrically) between the log detector outputs and the peak hold detectors. (This function is not indicated on Figure 13-1.). The

detector function was made selectable by an external two position switch; an unused command word bit and an internal relay could well have been used to retain the total digital control characteristic of the receiver, but at that point, a considerable amount of integration and re-layout would have been required; in light of the relative ease and economy of the manually switched function and the fact that digital incorporation of the function would pose no technological problems, the external switch was used.

The five peak detector amplifier outputs provide the inputs to five sample and hold circuits, the outputs of which are, in turn fed to a five port multiplexer. The multiplexer output, then can provide a succession of levels each representating a 20 kHz detector amplifier level at the time of its latest sampling by its associated sample and hold circuit. The output of the multiplexer (indicated in Figure 13-1 as a rotary switch) is fed to an analog to digital converter whose output consists of 7 bit parallel bytes which describe each successive sample quoted to it from a sample and hold circuit by the multiplexer. The timing of peak detector dumping, sample and hold sampling and dumping, multiplexer gating, and A to D sampling is critical to receiver operation. For each receiver sample interval of 500 usec or longer, the peak detectors are simultaneously sampled, each sample and hold level is gated in proper sequence to the A to D converter and read by it, and the peak detectors and sampling circuits are reset (or dumped) and re-enabled for the next sample interval. Hence, whether the receiver is scanning or operating in its fixed frequency mode, the digital output provides the end-of-interval

levels in each of the five contiguous 20 kHz channels once for each interval. The process is continuous; so long as the receiver is supplied with operational timing signals, the five levels are quantized and output once for each sample interval. Adjustment of the gain in each peak detector output circuit enables the quantized output to represent 1 dB steps of the peak detector levels.

Either AGC or fixed level attenuation can be added to the 150 MHz IF amplifiers through use of the appropriate digital control bits. The fixed attenuator levels available are 20 dB and 30 dB.

Receiver operational timing is under external control; the sample interval is determined by a "sequence command" input, and the output data byte transitions are timed by an "IF data shift" input. Hence, scan rate and output data rate can be established by operational requirements, to a maximum of 200 MHz/second and 70 kbits per second respectively.

Inputs to the receiver, all digital signals, specify receiver gain characteristic, mode of operation, operational frequency (or lower scan limit frequency), calibrator operation, and the timing of sample intervals and tuning increments.

Outputs from the receiver, also digital, provide a reference timing signal (1 MHz), power for ancillary equipment (the controller), the 20 kHz channel sample levels, the tuned frequency of the receiver, and status of the timing lock (synthesizer) function for

each sample interval. The last signal enables the sample level outputs to be inhibited in an external telemetry interface unit when the receiver is, for any reason, "out of lock" during a sample interval (e.g., receiver resetting to start frequency after end of scan).

The receiver input timing signals include sequence command, IF data shift, count enable, and reset signals. The sequence command and IF data shift signals, mentioned above, are continuously provided to the receiver. The count enable permits a 100 kHz timing increment for each sequence command when the mode signal indicates scanning mode operation; hence, timing increments can be suspended by the external receiver controller during a scan for insertion of framing, status, etc., in the output data stream. The reset signal commands the receiver to tune to the frequency specified by the reference frequency input word; hence each scan is terminated by the receiver controller.

The receiver includes a white noise generator capable of delivering a level of -189 dBW/Hz, $\pm$ 1 dB throughout the tuning range of the receiver. Schematics, drawings and parts lists for the receiver are furnished as a separate end item under this AAFE project and should be consulted for detailed information on receiver circuitry and components. Table 13-1 lists pertinent drawings furnished to the office of the COTR.

TABLE 13-1

AAFE MAN-MADE NOISE EXPERIMENT
DEMONSTRATION RECEIVER DRAWINGS

| WJ DWG NO | SIZE | SHEETS | TITLE |
|---|---|---|---|
| 5982A | F | 1 | Output Card Type 791246 |
| 5987 | F | 1 | Relay Driver Type 791234 |
| 5988 | F | 1 | Peak Hold Detector/Attenuator Driver Part 17321 |
| 5990 | F | 1 | Second Synthesizer Type 791251 |
| 23548 | B | 1 | 2 GHz Oscillator Part 17440 |
| 33588 | C | 1 | Converter Schematic Diagram Type 71392 |
| 33596 | C | 1 | Impulse Generator Type 791229 |
| 42369 | D | 1 | YIG Driver Type 791238 |
| 42391 | D | 1 | Log IF Part 17318 |
| 42392 | D | 1 | 4350 MHz IF Amplifier Type 71391 |
| 42398 | D | L | Integrating Detector Type 791135 |
| 42399 | D | 1 | 1950 MHz IF Amplifier Type 71390 |
| 42400 | D | 1 | Bias Card Type 791125 |
| 42402 | D | 1 | YIG Phase Detector Type 17357 |
| 42405 | D | 1 | Phase Lock Card Type 791103 |
| 42406 | D | 1 | 2.1 GHz Source Type 791093 |
| 42414 | D | 1 | 124 MHz VXCO Type 7778 |
| 61048 | - | 1 | Arithmetic Card Type 791253 |
| 61064 | - | 1 | IF/Video Type 791253 |
| 61066 | - | 2 | AAFE Receiver Main Chassis Schematic Diagram |
| 61068 | - | 1 | First Synthesizer Type 791252 |
| 61746 | A | 8 | 16 Bit D/A Converter Printed Wiring Board |

## 13.3 The Controller and Interface Unit

In order to provide the capability of operating over extended periods in response to pre-loaded sequences of control signals, and to provide simplified "outside world" interface requirements, a Command Decoder, Sequencer, Controller and Telemetry Interface unit (CDSC/TI) was designed and constructed in conjunction with the project. This unit, which interfaces the receiver and the digital signal processors which provide control and output terminals for it, would be integral with the spaceborne receiver derived from this project. A number of considerations weighed against that choice for the demonstration hardware, however; not least among them was the fact that when it was necessary to specify the receiver to the subcontractor interface requirements were fluid and unresolved.

Functionally, the CDSC/TI provides storage for a sequence of operational receiver commands, it interprets those commands, and it generates the control signals which cause them to be executed at specified times. In addition, the CDSC/TI interprets receiver status signals and formats the output data stream to provide flags or framing bytes and status data in addition to receiver amplitude measurements. Inputs to the CDSC consist of commands and a command timing signal (from a source simulating a spacecraft command receiver), a continuous stream of output data, timing and status signals from the experiment receiver, playback signals from a tape recorder, and a primary performance timing signal (from a source simulating a down-link data multiplexer or other experiment synchronizer). Outputs from the CDSC/TI consist of control

signals made available to the experiment receiver, an experiment associated data tape record/playback unit and an antenna select unit, and a continuous stream of data signals (to a device simulating a down-link data multiplexer or modulator and a tape record/playback unit).

Figure 13-5 is a block diagram of the CDSC/TI indicating internal functions and external interfaces. Figure 13-6 is a plan drawing of the CDSC/TI showing top and front views. Its external dimensions are approximately 43 cm x 26 cm x 5 cm. It can be mounted on the fan housing cover of the experiment demonstration receiver; adhesive backed hood and loop fastening material (manufactured by the 3M Co.) has been placed on the mating surfaces of the receiver and the CDSC/TI to facilitate such mounting.

The command input to the CDSC/TI can be either serial or parallel but in the event that parallel input is to be used, CDSC/TI chips C1, C2, C3, C4, C5, C6 and C7 must be removed for circuit protection; command read time is coincident with "0" to "1" transitions (leading edge) of the serial- or parallel-clock (strobe) signal as appropriate. Table 13-2 presents the CDSC/TI command structure, bit by bit. (Command bit lines, or circuits, are identified on the block diagram and in wire lists by "PO" numbers; hence, bit number 9, the least significant bit of the command execute time definition byte structure, occurs or wire "P09" in the CDSC/TI). The command structure includes neither redundancy nor parity; such functions are unnecessary in establishing conceptual feasibility, and they could readily be

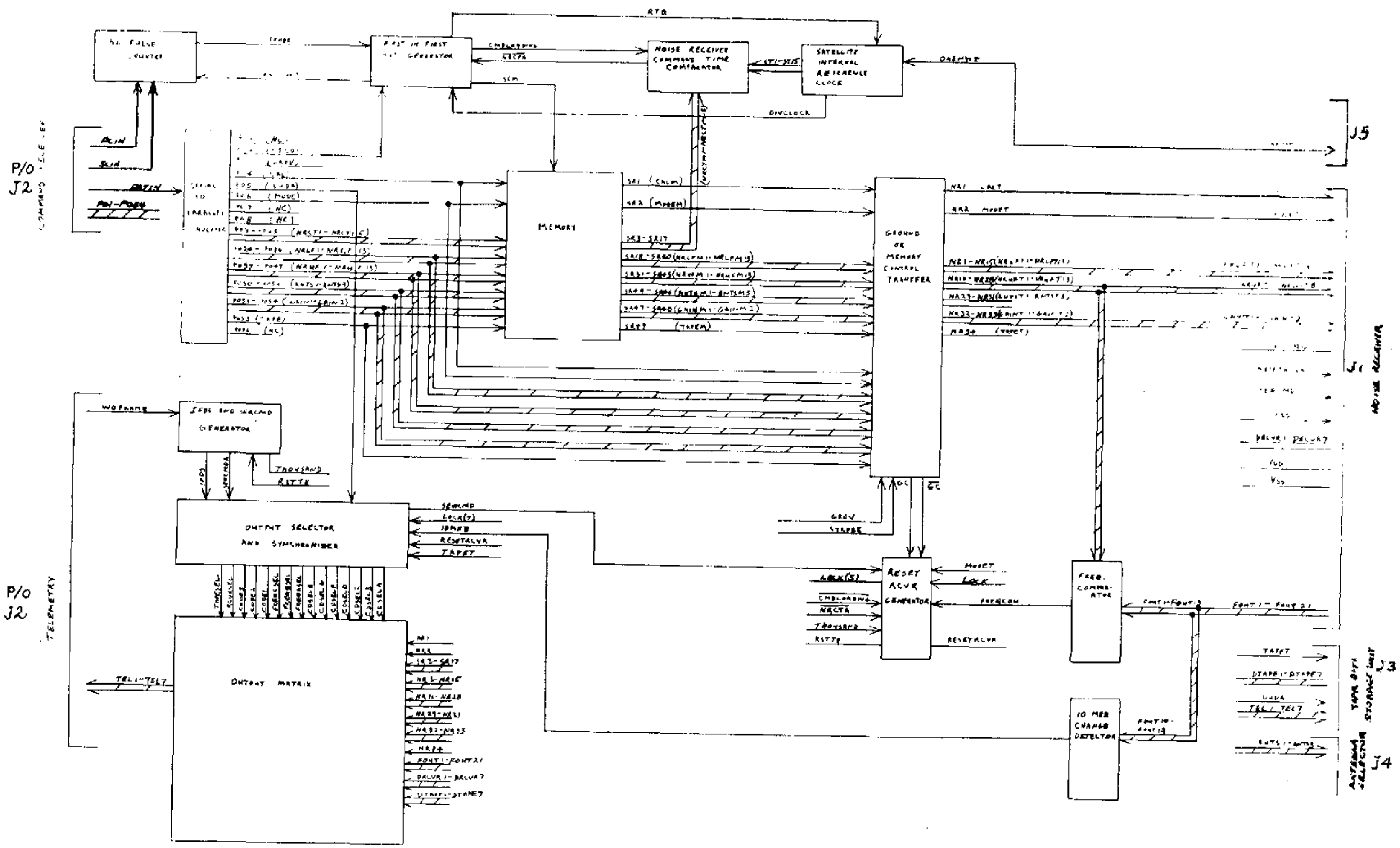
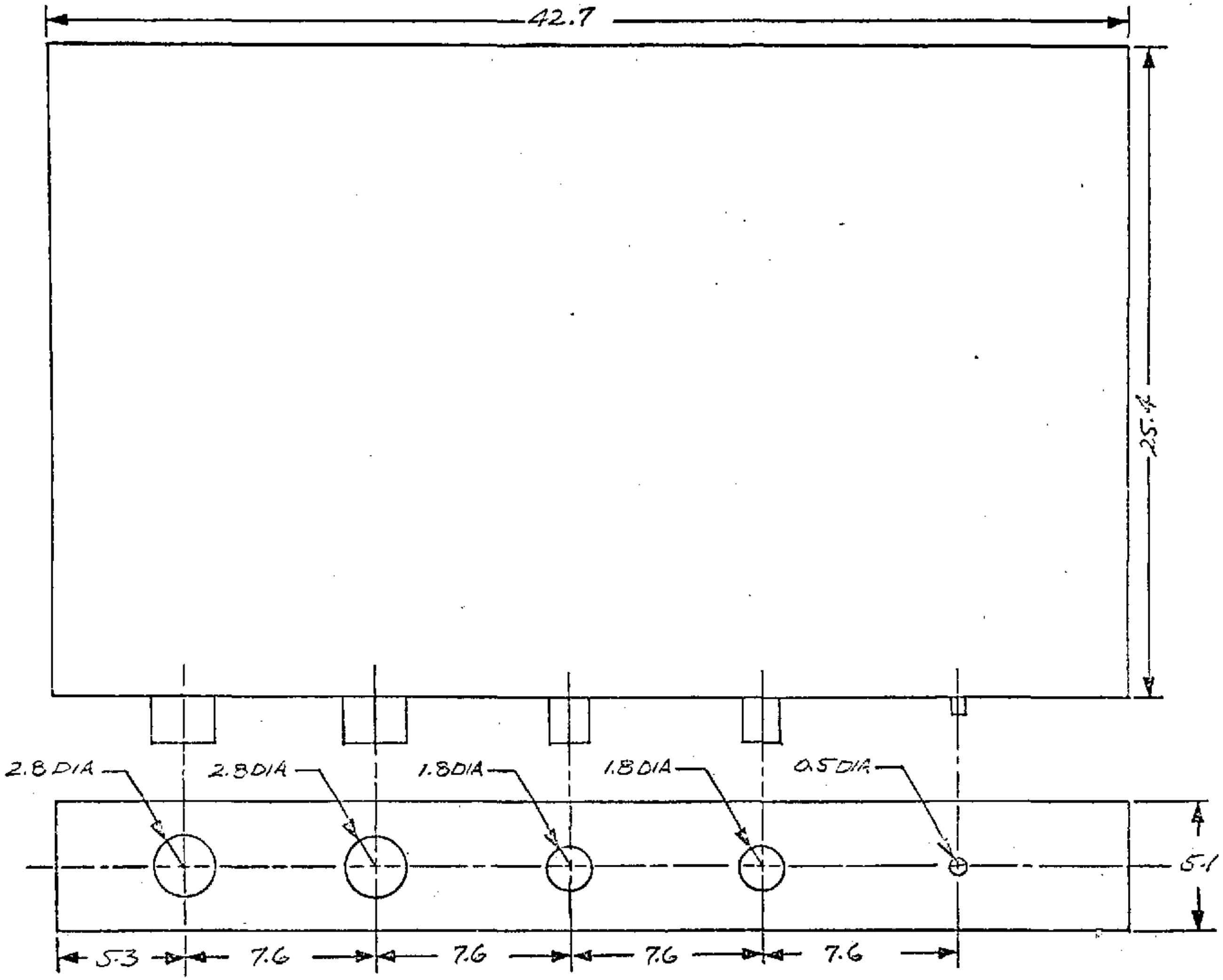



FIGURE 13-5 CDSC/TI FUNCTIONAL BLOCK DIAGRAM




NOTES

ALL DIMENSIONS GIVEN IN CENTIMETERS TOLERANCES ± 0.2 CM. DIMENSIONS NOT TO INCLUDE SCREW HEAD PROTUSIONS.

FIGURE 13-6   CSDC/TI CHASSIS DRAWING

TABLE 13-2

CDSC/TI COMMAND WORD ORGANIZATION

| COMMAND BIT(PO) | CODE | FUNCTION | |
|---|---|---|---|
| 1 | | Not Used | |
| 2 | STCD | Store Command | |
| 3 | GROV | Ground Override | |
| 4 | CAL | Calibrator On | |
| 5 | DUDA | Dump Data (Playback) | |
| 6 | MODE | Mode Fixed (Frequency or Scan) | |
| 7 | | Not Used | |
| 8 | | Not Used | |
| 9 | NRCT1 | Command Execute Time (LSB) | |
| 10 | NRCT2 | " " " " | |
| 11 | NRCT3 | " " " " | |
| 12 | NRCT4 | " " " " | |
| 13 | NRCT5 | " " " " | |
| 14 | NRCT6 | " " " " | |
| 15 | NRCT7 | " " " " | |
| 16 | NRCT8 | " " " " | |
| 17 | NRCT9 | " " " " | |
| 18 | NRCT10 | " " " " | |
| 19 | NRCT11 | " " " " | |
| 20 | NRCT12 | " " " " | |
| 21 | NRCT13 | " " " " | |
| 22 | NRCT14 | " " " " | |
| 23 | NRCT15 | Command Execute Time (MSB) | |
| 24 | NRLF1 | Lower Frequency (MSB) | Fixed Frequency (MSB) |
| 25 | NRLF2 | " " " | " " " |
| 26 | NRLF3 | " " " | " " " |
| 27 | NRLF4 | " " " | " " " |
| 28 | NRLF5 | " " " | " " " |
| 29 | NRLF6 | " " " | " " " |
| 30 | NRLF7 | " " " | " " " |
| 31 | NRLF8 | " " " | " " " |
| 32 | NRLF9 | " " " | " " " |
| 33 | NRLF10 | " " " | " " " |
| 34 | NRLF11 | " " " | " " " |
| 35 | NRLF12 | " " " | " " " |
| 36 | NRLF13 | Lower Frequency (LSB) | " " " |
| 37 | NRUF1 | Upper Frequency (MSB) | " " " |
| 38 | NRUF2 | " " " | " " " |
| 39 | NRUF3 | " " " | " " " |
| 40 | NRUF4 | " " " | " " " |
| 41 | NRUF5 | " " " | " " " |
| 42 | NRUF6 | " " " | " " " |
| 43 | NRUF7 | " " " | " " " |
| 44 | NRUF8 | " " " | Fixed Frequency (LSB) |
| 45 | NRUF9 | " " " | " " " |
| 46 | NRUF10 | " " " | " " " |
| 47 | NRUF11 | " " " | " " " |
| 48 | NRUF12 | " " " | " " " |
| 49 | NRUF13 | Upper Frequency (LSB) | " " " |
| 50 | ANTS1 | Antenna Select (MSB) | |
| 51 | ANTS2 | Antenna Select (MSB) | |
| 52 | ANTS3 | Antenna Select (LSB) | |
| 53 | GAIN1 | Gain (Attenuation) (MSB) | |
| 54 | GAIN2 | Gain (Attenuation) (LSB) | |
| 55 | TAPE | Tape Recorder On | |
| 56 | | Not Used | |

implemented between the command source and the CDSC/TI input. There are four unused bits in the structure; during the development of the command, they were originally used. Hence, although the original 56 bit organization system was retained for convenience, the actual size of the command is 52 bits.

If serial command input is used, bits must be supplied for the four non-functional bits. For serial input to the CDSC/TI the input data rate must be $\leq$100 kbit per second; a serial clock input (SCIN) pulse is used to strobe each bit, and each of its "1" levels must $\geq$ 2 μ seconds and $\leq$ 8 μ seconds, with leading edges occurring at least 2 μ seconds after serial data input bit transitions. A minimum period between successive commands of 50 m seconds is required. The loading order for serial commands is high order first; i.e., bit 56 is the first in the stream, and bit 1 is the last.

As stated above, a number of integrated circuits must be removed from the CDSC/TI if commands are to be loaded in parallel. The input data rate must $\leq$ 100,000 commands/second; a parallel clock input (PCIN) pulse is used to strobe each command, and each of its "1" levels must $\geq$ 2 μ seconds and $\leq$ 8 μ seconds.

As each command is loaded, its store (STCD), tape playback (DWDA) and immediate execute (GROU) bits are interpreted the appropriate responses are generated. The GROU (for "ground override") bit produces the control transfer switch to output the receiver control bits of the command immediately; otherwise, these bits are stored in the CDSC/TI memory, which consists of a 64 bit shift register for each stored bit.

Each "new" command of a sequence of commands to be stored is shifted into the registers; if a period of 1 minute occurs without a new command, the memory registers are incremented until the first new command of the sequence is at the output port (64th stages); an internal clock then is reset to zero, and the time comparator circuits commence operation. When the specified execute time of the command at the 64th memory position is recognized by the time comparator, memory registers are incremented one bit, and control bits of the command to be executed are transferred to the output transfer circuits and hence to the receiver.

When the receiver operates in its scanning mode, the bits of the output command specifying the upper scanning frequency limit (NRUFT-1, -13) are compared in the CDSC/TI on a continuous basis with the 13 high order bits of the frequency word from the receiver (FOUT-1, -13). As a result of this comparison, a reset (RESETRCVR) control signal is generated at the upper frequency of each scan. Reset signals also occur upon command changes, and when the receiver is operating in its fixed frequency mode, every 1000 sample intervals.

For every sample interval, the CDSC/TI requires a word frame (WDFRAME) signal from the data output (TEL -1, -7) sink (or other appropraite rate controlling source). For each word frame pulse (which can be accepted at a maximum specified rate of 10,000 per second), a data byte is output and a sample interval signal (SEQCMD) is provided to the receiver. Each data output word consists of either a 20 kHz channel measurement level or one of

13 flag and status structures, selected by the output matrix multiplexer. Output selection is controlled by the output selector/synchronizer circuitry. Table 13-3 defines the 13 flag and status outputs. The CODE A byte is always output in pairs; a pair of CODE A bytes indicate a reset receiver function and that the following 7 bytes are CDSEL A thorugh CDSEL G. The CODE B byte is an idle flag; it is output continuously for the period required for each receiver reset, command change, etc. The CODE C byte, also output in pairs is an indication of a 10 MHz crossover by the receiver, and it is always followed by FREQ A through FREQ C bytes, which indicate the crossover frequency. It should be noted that the receiver should not output levels higher than $1001111_2$ $(79_{10})$ under any circumstances; hence, the flag bytes (CODE A, CODE B and CODE C) contain unique structures for identification. Parity, redundancy (excepting the flag bytes) and other error detection or correction measures were not incorporated in the CDSC/TI output.

The remaining CDSC/TI functions are straightforward. Additional information is contained in the drawings package furnished to the COTR. Table 13-4 lists the drawings which describe this unit. Figure 13-7 is a diagram which indicates the locations and functions of connectors on the CDSC/TI. Table 13-5 indicates pin assignments in terms of drawing code designations for CDSC/TI input/output connectors.

Throughout the CDSC/TI, values (e.g., time) are expressed in Johnson code; Table 13-6 provides conversion by digit between decimal, BCD and Johnson codes.

TABLE 13-3

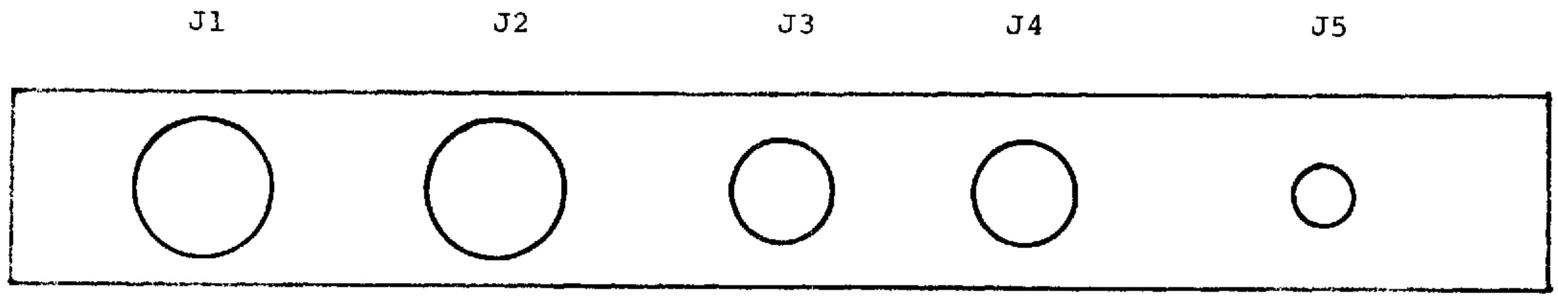
CDSC/TI FLAG AND STATUS BYTE STRUCTURES

| BYTE | OUTPUT 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| CODE A | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CDSEL A | CAL | MODE | NRCT1 | NRCT2 | NRCT3 | NRCT4 | NRCT5 |
| CDSEL B | NRCT6 | NRCT7 | NRCT8 | NRCT9 | NRCT10 | NRCT11 | NRCT12 |
| CDSEL C | NRCT13 | NRCT14 | NRCT15 | NRLF1 | NRLF2 | NRLF3 | NRLF4 |
| CDSEL D | NRLF5 | NRLF6 | NRLF7 | NRLF8 | NRLF9 | NRLF10 | NRLF11 |
| CDSEL E | NRLF12 | NRLF13 | NRUF1 | NRUF2 | NRUF3 | NRUF4 | NRUF5 |
| CDSEL F | NRUF6 | NRUF7 | NRUF8 | NRUF9 | NRUF10 | NRUF11 | NRUF12 |
| CDSEL G | NRUF13 | ANTS 1 | ANTS2 | ANTS3 | GAIN1 | GAIN2 | TAPE |
| CODE B | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| CODE C | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| FREQ A | FOUT1 | FOUT2 | FOUT3 | FOUT4 | FOUT5 | FOUT6 | FOUT7 |
| FREQ B | FOUT8 | FOUT9 | FOUT10 | FOUT11 | FOUT12 | FOUT13 | FOUT14 |
| FREQ C | FOUT15 | FOUT16 | FOUT17 | FOUT18 | FOUT19 | FOUT20 | FOUT21 |

## TABLE 13-4

## CDSC/TI DRAWINGS

| DWG. NO. | SIZE | SHEETS | TITLE |
|---|---|---|---|
| 1375 | D | 1 | Output Matrix 2 |
| 1376 | D | 1 | Memory 1 |
| 1377 | D | 1 | Command Time Comparator |
| 1378 | D | 1 | Ground or Memory Control Transfer |
| 1379 | D | 1 | First In/First Out Generator |
| 1380 | D | 1 | 56 Pulse Counter |
| 1381 | D | 1 | IFDS & SEQ CMD Generator |
| 1382 | D | 1 | Memory 2 |
| 1383 | D | 1 | Frequency Comparator |
| 1384 | D | 1 | 10 MHz Change Detector |
| 1385 | D | 1 | Internal Reference Clock |
| 1386 | D | 1 | Serial In/Parallel Out Converter |
| 1387 | D | 1 | Thousand Counter |
| 1388 | D | 1 | Telemetry Interface (TI) 1 |
| 1389 | D | 1 | CDSC/TI Block Diagram |
| 1390 | D | 1 | Reset Receiver Generator |
| 1391 | D | 1 | Telemetry Interface (TI) 2 |
| 1392 | D | 1 | Selector/Synchronizer 1 |
| 1393 | D | 1 | Selector/Synchronizer 2 |
| 1394 | B | 1 | Discrete Component Assemblies |




CDSC/TI CONNECTOR PANEL

| CONNECTOR | TO | TYPE* | MATE |
|---|---|---|---|
| J1 | Experiment Receiver | 348-40E18-85P1 | 348-46E18-85S1 |
| J2 | Command Receiver & Telemetry | 348-40E18-85S2 | 348-46E18-85P1 |
| J3 | Tape Unit | 348-40E10-12P2 | 348-46E10-12S2 |
| J4 | Antenna Selector | 348-40E10-12S1 | 348-46E10-12P1 |
| J5 | Noise Receiver Reference Clock | SMA P/N 901-112 | SMA P/N 901-107 |

* Amphenol

FIGURE 13-7 CDSC/TI CONNECTOR LOCATION DIAGRAM

TABLE 13-5

CDSC/TI CONNECTOR PIN ASSIGNMENTS

CONNECTOR J1 (TO EXPERIMENT RECEIVER)

| PIN | | | PIN | | | PIN | |
|---|---|---|---|---|---|---|---|
| 1 | LOCK | | 31 | NRLFT5 | | 61 | PIN 61 NU |
| 2 | GAINT1 | | 32 | NRLFT4 | | 62 | PIN 62 NU |
| 3 | GAINT2 | | 33 | NRLFT3 | | 63 | |
| 4 | MODET | | 34 | NRLFT2 | | 64 | |
| 5 | SEQCMD | | 35 | NRLFT1 | MSB | 65 | |
| 6 | IFDS | | 36 | CALT | | 66 | |
| 7 | DRCVR7 | LSB | 37 | FOUT1 | MSB | 67 | |
| 8 | DRCVR6 | | 38 | FOUT2 | | 68 | |
| 9 | DRCVR5 | | 39 | FOUT3 | | 69 | |
| 10 | DRCVR4 | | 40 | FOUT4 | | 70 | |
| 11 | DRCVR3 | | 41 | FOUT5 | | 71 | |
| 12 | DRCVR2 | | 42 | FOUT6 | | 72 | |
| 13 | DRCVR1 | MSB | 43 | FOUT7 | | 73 | |
| 14 | RESETRCVR | | 44 | FOUT8 | | 74 | |
| 15 | NRUFT8 | LSB | 45 | FOUT9 | | 75 | |
| 16 | NRUFT7 | | 46 | FOUT10 | | 76 | |
| 17 | NRUFT6 | | 47 | FOUT11 | | 77 | |
| 18 | NRUFT5 | | 48 | FOUT12 | | 78 | |
| 19 | NRUFT4 | | 49 | FOUT13 | | 79 | |
| 20 | NRUFT3 | | 50 | FOUT14 | | 80 | |
| 21 | NRUFT2 | | 51 | FOUT15 | | 81 | |
| 22 | NRUFT1 | | 52 | FOUT16 | | 82 | |
| 23 | NRLFT13 | | 53 | FOUT17 | | 83 | |
| 24 | NRLFT12 | | 54 | FOUT18 | | 84 | |
| 25 | NRLFT11 | | 55 | FOUT19 | | 85 | |
| 26 | NRLFT10 | | 56 | FOUT20 | | | |
| 27 | NRLFT9 | | 57 | FOUT21 | LSB | | |
| 28 | NRLFT8 | | 58 | GND | | | |
| 29 | NRLFT7 | | 59 | $V_{DD}$ | | | |
| 30 | NRLFT6 | | 60 | CNT ENAB | | | |

TABLE 13-5 (CONT)

CDSC/TI CONNECTOR PIN ASSIGNMENTS

CONNECTOR J2 (TO COMMAND RECEIVER AND TELEMETRY)

| PIN | | PIN | | PIN | |
|---|---|---|---|---|---|
| 1 | PO1 | 31 | PO31 | 61 | TEL2 |
| 2 | PO2 | 32 | PO32 | 62 | TEL3 |
| 3 | PO3 | 33 | PO33 | 63 | TEL4 |
| 4 | PO4 | 34 | PO34 | 64 | TEL5 |
| 5 | PO5 | 35 | PO35 | 65 | TEL6 |
| 6 | PO6 | 36 | PO36 | 66 | TEL7 LSB |
| 7 | PO7 | 37 | PO37 | 67 | WDFRAME |
| 8 | PO8 | 38 | PO38 | 68 | GND |
| 9 | PO9 | 39 | PO39 | 69 | IFDS |
| 10 | PO10 | 40 | PO40 | 70 | DUMPCDSC |
| 11 | PO11 | 41 | PO41 | 71 | FIXED RST |
| 12 | PO12 | 42 | PO42 | 72 | CNTENABEXT |
| 13 | PO13 | 43 | PO43 | 73 | |
| 14 | PO14 | 44 | PO44 | 74 | |
| 15 | PO15 | 45 | PO45 | 75 | |
| 16 | PO16 | 46 | PO46 | 76 | |
| 17 | PO17 | 47 | PO47 | 77 | |
| 18 | PO18 | 48 | PO48 | 78 | |
| 19 | PO19 | 49 | PO49 | 79 | |
| 20 | PO20 | 50 | PO50 | 80 | |
| 21 | PO21 | 51 | PO51 | 81 | |
| 22 | PO22 | 52 | PO52 | 82 | |
| 23 | PO23 | 53 | PO53 | 83 | |
| 24 | PO24 | 54 | PO54 | 84 | |
| 25 | PO25 | 55 | PO55 | 85 | |
| 26 | PO26 | 56 | PO56 | | |
| 27 | PO27 | 57 | PCIN | | |
| 28 | PO28 | 58 | DATIN | | |
| 29 | PO29 | 59 | SCIN | | |
| 30 | PO30 | 60 | TELI MSB | | |

TABLE 13-5 (CONT)

CDSC/TI CONNECTOR PIN ASSIGNMENTS

CONNECTOR J3 (TO TAPE UNIT)

| PIN | | |
|---|---|---|
| 1 | DTAPE1 | MSB |
| 2 | DTAPE2 | |
| 3 | DTAPE3 | |
| 4 | DTAPE4 | |
| 5 | DTAPE5 | |
| 6 | DTAPE6 | |
| 7 | DTAPE7 | LSB |
| 8 | TAPET | |
| 9 | DUDAT | |
| 10 | PIN10T | NU |
| 11 | PIN11T | NU |
| 12 | GND | |

CONNECTOR J4 (TO ANTENNA SELECTOR)

| PIN | |
|---|---|
| 1 | ANTST1 |
| 2 | ANTST2 |
| 3 | ANTST3 |
| 4 | ANTST4 |
| 5 | ANTST5 |
| 6 | ANTST6 |
| 7 | ANTST7 |
| 8 | ANTST8 |
| 9 | ANTST9 |
| 10 | ANTST10 |
| 11 | ANTST11 |
| 12 | GND |

# TABLE 13-6

## CODE CONVERSIONS

| DECIMAL | BCD | JOHNSON CODE |
|---|---|---|
| 0 | 0000 | 11111 |
| 1 | 0001 | 01111 |
| 2 | 0010 | 00111 |
| 3 | 0011 | 00011 |
| 4 | 0100 | 00001 |
| 5 | 0101 | 00000 |
| 6 | 0110 | 10000 |
| 7 | 0111 | 11000 |
| 8 | 1000 | 11100 |
| 9 | 1001 | 11110 |
| | MSB LSB | LSB MSB |

## 13.4 Performance

Operational characteristics of the receiver and its associated control unit were established through a series of tests and functional exercises undertaken during and after integration of the two devices. These tests were begun in November 1973 and continued through June 1974. Three test plans were involved in the tests, and tests not included in the test plans also were performed. However, the test and performance demonstration work carried out in connection with the project was by no means exhaustive. The major operational features and performance characteristics were defined, but in depth study and analysis of the capabilities and limitations, the strong and weak points, of the hardware were not possible. (To a great extent, this was the case under the original project concepts, but the problems encountered in completing the receiver, with attendant delays and rescheduling requirements, certainly imposed additional limitations on the scope of hardware use and study).

The static and RF performance characteristics of the receiver were established and demonstrated through tests performed at the Watkins-Johnson Co. facilities in Gaithersburg. A formal set of tests were used to satisfy NSL of the acceptability of performance. Table 13-7 summarizes the results of the W-J tests and provides comparison between measured performance parameters and those of the original receiver specification. The receiver was found to comply with original requirements with the following exceptions:

# TABLE 13-7
# AAFE MAN MADE NOISE DEMONSTRATION RECEIVER CHARACTERISTICS AND PERFORMANCE SUMMARY

| SPECIFICATION | | | | PERFORMANCE | |
|---|---|---|---|---|---|
| PARAGRAPH | REQUIREMENT | VALUE | UNITS | VALUE | UNITS |
| 3.1 | General | --- | --- | --- | --- |
| 3.2.1 | Max. Dimen. | 55 | cm | <43 | cm |
| 3.2.2 | Volume | $20\times10^3$ | $cm^3$ | $<20\times10^3$ | $cm^3$ |
| 3.2.3 | Weight | 12 | kg | 12.6 | kg |
| 3.2.4 | Connectors | --As Specified-- | | --- | --- |
| 3.3 | Opn. Temp. | 10-50 | Deg. C | 10-50 | Deg. C |
| | Opn Press. | $0\text{-}10\times10^3$ | m Alt. | --- | --- |
| 3.4.1 | Input Imp. | 50 | Ω | 50 | Ω |
| 3.4.2 | Input Voltage | $28\pm4.2$ | V | $28\pm5$ | V |
| | Input Power | 35 Max. | Watts | 70 Max. | Watts |
| 3.4.3 | Power Out. | 14;1 | V;W | 14;1 | V;W |
| 3.4.4 | Command & Control | --As Specified-- | | --- | --- |
| 3.4.5 | Data | --As Specified-- | | --- | --- |
| 3.5.1 | Freq. Range | 0.4-12.4 | GHz | 0.4-12.4 | GHz |
| 3.5.2 | Dispersion | 12.0 | GHz | 12.0 | GHz |
| 3.5.3 | Disp. Rate | 200 | MHz/Sec | 200 | MHz/Sec |
| 3.5.4 | Freq. Resolution | 20 | kHz | 20 | kHz |
| 3.5.5 | Timing Increment | 100 | kHz | 100 | kHz |
| 3.5.6 | Freq. Stab. | $\pm1/10^6$ | pt/Hz/day | | |
| 3.5.7 | Static Selectivity | 20 | kHz | 20 | kHz |
| 3.5.8 | Input VSWR | 3.0:1 | --- | $\leq3.0:1$ | --- |
| 3.5.9 | Dynamic Range | $\geq65$ | dB | $\geq65$ | dB |
| | 1 dB Compression | $\geq-40$ | dBm | $\leq-35$ | dBm |
| 3.5.10 | 3rd Order Intercept | $\geq-30$ | dBm | $\leq-25$ | dBm |
| 3.5.11 | Image Rejection | -65 | dB | <-90 | dB |
| 3.5.12 | Sensitivity | | | | |
| | N.F.<1.0GHz | 6 | dB | 6 | dB |
| | N.F.$\geq$1.0GHz | 10 | dB | 11 | dB |
| 3.5.13 | Amp. Resolution | 1 | dB | | |
| 3.5.14 | Gain Stab. | $\pm4$ | dB | $\leq4$ | dB |
| 3.5.15 | Freq. Acc. | $\pm10$ | kHz | $\leq2$ | kHz |
| 3.5.16 | Amp. Col. | $\geq-116$ | dBm | -106 | |
| | | $\pm1$ | dB | $\pm$1dB | |

- o Power consumption was appreciably in excess of the 35 watt specified maximum;

- o Noise figure exceeded specified limits by 1.0 dB at the upper regions of the receiver's tuning range.

The excessive power consumption was found to result from internal power consumption of the receiver's modular power supplies. Functional circuit power requirements in the receiver were found to be approximately 32 watts maximum; the overall power supply efficiency, with an input of 28 volts, was less than 50%. The regulation characteristics of the supplies result in a very evident relationship between prime supply voltage and efficiency; 22 to 24 volts was found to result in a 5% to 10% increase in operating efficiency (relative to the 28V input case).

The unexpected thermal output from the receiver's modular power supplies caused notable increases in the receiver chassis temperatures in the vicinity of the power compartment. Subsequent to the initial W-J performance tests, which included an environmental temperature test, a thermal shock test was performed to further demonstrate performance under specified thermal requirements. The frequency of the first (YIG tuned) local oscillator was monitored, and its stability was recorded. The receiver was fixed tuned to 2.1000 GHz, and the characteristics tabulated in Table 13-8 were noted. The overall variation in local oscillator frequency during this test was less than 8 kHz.

TABLE 13-8

RECEIVER THERMAL SHOCK TEST RESULTS

| TIME (MIN) | AMBIENT TEMP. (°C) | YTO FREQUENCY (GHz) |
|---|---|---|
| $T_0$ | +25 | |
| $T_0 + 60$ | +25 | 6.4500002 |
| $T_1$ | +10 | |
| $T_1 + 60$ | +10 | 6.4500027 |
| $T_1 + 73$ | +50 | 6.4500020 |
| $T_1 + 75$ | +50 | 6.4500008 |
| $T_1 + 77$ | +50 | 6.4499996 |
| $T_1 + 80$ | +50 | 6.4499984 |
| $T_1 + 85$ | +50 | 6.4499969 |
| $T_1 + 90$ | +50 | 6.4499959 |
| $T_1 + 95$ | +50 | 6.4499955 |
| $T_1 + 100$ | +50 | 6.4499952 |
| $T_1 + 105$ | +50 | 6.4499951 |
| $T_1 + 110$ | +50 | 6.4499952 |
| $T_1 + 120$ | +50 | 6.4499952 |
| $T_1 + 125$ | +50 | 6.4499952 |
| $T_1 + 130$ | +50 | 6.4499952 (case temp = 78°) |

NOTE: $f_o$ = 2.1000 GHz

The power supply thermal output of the receiver was, nonetheless, the cause of continued concern to W-J, and when problems were encountered at a later date which resulted in receiver modifications, a fan and cooling vents were added to a receiver cover to provide convection cooling for the power supplies. This modification, according to W-J, was not necessary but provides a considerable thermal margin not present prior to its addition. The fan, it was pointed out, can be removed or left unpowered if necessary. In fact, the fan has its own power cord, and operates from a 110 VAC source.

The other noteworthy shortcoming of the receiver with respect to its original performance specification, as determined by the W-J tests, was in the area of operating noise figure. The maximum receiver noise figure was specified as 10 dB; at frequencies above 9 GHz, some measurements indicated higher noise levels. The receiver's performance in this area was established through use of a standard noise figure meter; the 150 MHz IF signal from the receiver was reduced to the noise figure meter input frequency through use of an intermediate receiver having a suitable output IF. With this installation, a variation of $\pm$ 1 dB from measurement to measurement was experienced, and the final performance values were obtained by averaging five or more measurements. The resultant data indicated a maximum noise figure of less than 11 dB, occurring at 12.4 GHz.

Supplementary acceptance tests were performed after delivery of the receiver to NSL and its integration with the CDSC/TI. As a result of the initial tests, the receiver was returned to W-J for further work. Corrective modifications were added, and the receiver was returned to NSL and retested. The NSL acceptance tests, were performed to establish the receiver's digital output characteristics, command and control responses, and command and data timing characteristics. The second series of tests established receiver conformance with requirements. It is noteworthy that W-J performed in-house tests of the performance characteristics verified by their earlier tests, after addition of the corrective modifications. The Watkins-Johnson Co. affirmed that those modifications in no way affected the earlier performance data, and a letter to that effect was provided to NSL.

Figure 13-8 illustrates the graphic data resulting from NSL receiver tests. In this figure, a montage of the five graphs resulting from a single receiver test is presented, the test was performed (in accordance with para. 3.2.5 of the test plan) to determine the response of the center 20 kHz channel to four discrete input signal levels. For this test, a CW source was tuned to the receiver fixed tuned frequency. Its level was adjusted for a nominal -151 dBW level at the receiver input. The CDSC/TI output was monitored by a Computer Automation model 816 computer which accumulates the quantities of measurements at each output level (0-70) in each 20 kHz channel. Ten thousand measurements were accumulated for each channel, and the results were

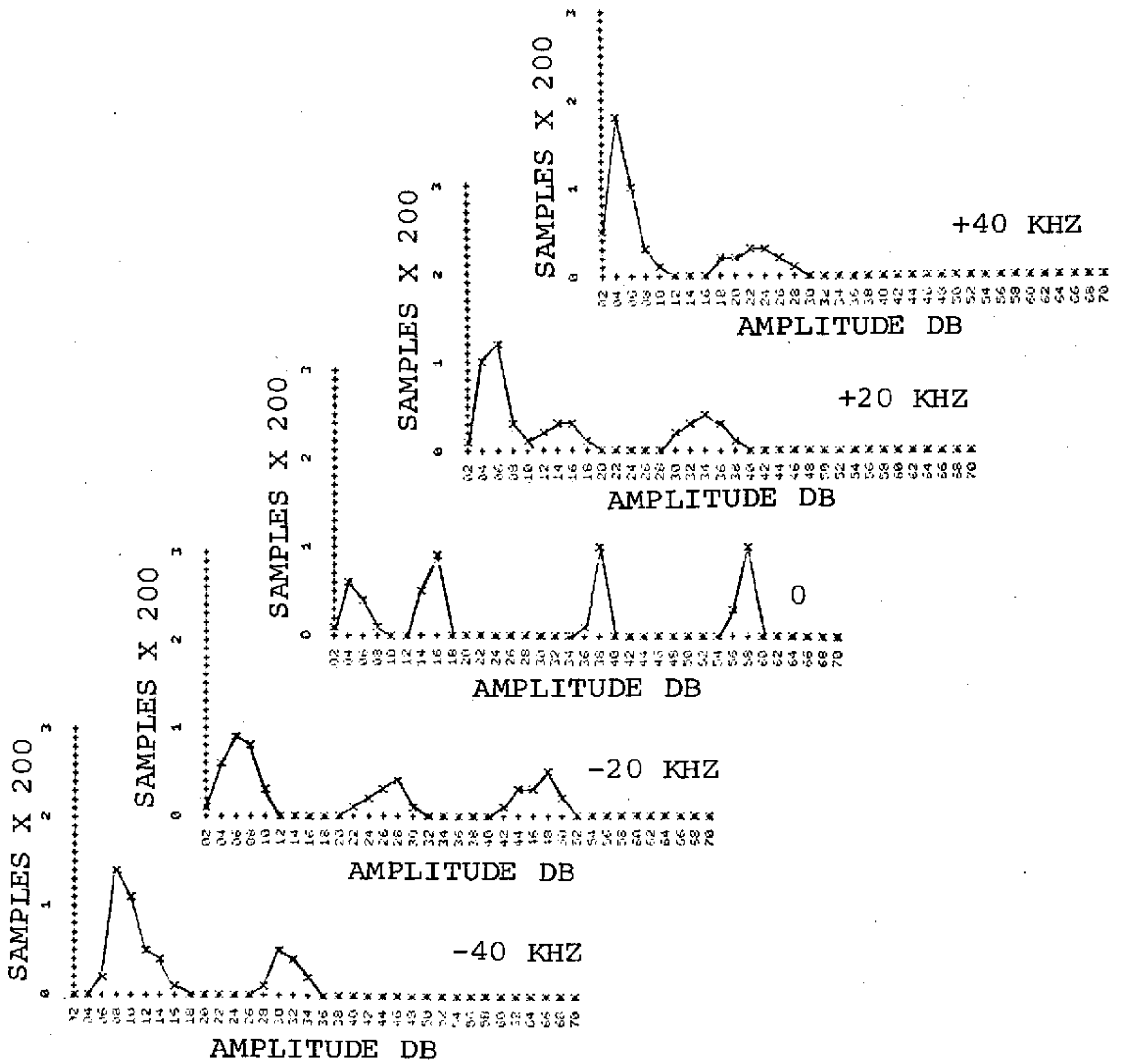



FIGURE 13-8 RECEIVER AMPLITUDE RESPONSES, TYPICAL

output via printer in amplitude distributions for each channel. During the sample collection interval, the input signal level was incremented to -141, -131 and -121 dBW levels at manually spaced sub-intervals. Hence, the graphic output for the center channel indicates four distinct responses, the highest being that for the -121 dBW signal level. Skirt response characteristics of the adjacent channels, and fortuitous modulation levels of the input signal resulted in discernible responses in all channels to the input signal at its higher levels. This graphic output established the amplitude tracking of the center channel.

Similar graphic outputs were obtained to establish or verify other aspects of receiver performance. Performance of the internal calibration noise generator was verified; frequency accuracy was rechecked; and minimum discernible signal (MDS) levels were established.

It was determined during the course of these tests that the CW MDS levels in the 400-500 MHz region were approximately -140 dBW, as indicated by a clear 2 dB upward shift in the level of maximum response in the receiver center channel. This represents a S/N of approximately 19 dB, based on the 500 MHz noise figure measurement of 4.2 dB. It is noteworthy that, with the receiver's noise calibrator used as a signal source, a clear shift of 2 dB in maximum response amplitude occurred with an input S/N of 10 dB.

During the course of the project, a second detector function, an integrating detector, was added to the receiver; amplitude

response tests showed that the CW signal MDS levels in the 400-500 MHz region with this detector were approximately -143 dBW representing a S/N of 16 dB, or a 3 dB improvement over the peak detector response. There was no discernible change in MDS level or S/N in response to white noise excitation relative to that encountered for CW signals.

In order to facilitate input signal tuning and like functions, an analog output was created during the tests. This output was obtained from the signal path from the five channel multiplexer to the A/D converter; this signal was used as the vertical input to a standard laboratory oscilloscope whose horizontal trigger was obtained from the SEQ CMD or RESET signals from the CDSC/TI as appropriate. Hence, analog levels from each successive sample were displayed, and the oscilloscope time base and triggering could be adjusted to represent frequency vs. distance. With this output in use, visual MDS levels were 1 to 3 dB lower than those resulting from digitized amplitude statistics. (Quantization error and the "correlation processing" resulting from correlated sweep triggering readily accounted for this difference in sensitivity).

Receiver tests and exercises were performed after its integration with the CDSC/TI. A sequence of tests also were performed specifically to verify performance of individual CDSC/TI circuitry. The unit performed as required during all tests, and its performance during the receiver tests further verified its functional conformance with requirements.

The receiver also was operated from time to time during the course of its integration and test at NSL under the control of a unit designed and fabricated by W-J for in-house use and furnished with the receiver on a loan basis to facilitate receiver integration. This unit provided switch selection of receiver operating mode, frequencies (operating fixed frequency or high and low scanning mode frequencies) and other variables. It was used particularly in conjunction with the analog oscilloscope display described above to permit rapid "spectrum searches" of the receiver's immediate environment with appropriate antennas. The unit was not, however, reliable; all performance tests and evaluations were completed using the CDSC/TI and its input/output computer interface.

## 14. UNSOLVED PROBLEMS

The primary purpose for the AAFE project was to design and define an experiment to measure and use information and data concerning the radio frequency interference environment which exists at orbit altitudes. The experiment designed under this project should provide a baseline from which a "flyable" experiment can be realistically defined and executed. However, a number of areas of the development and execution of an operational experiment remained unaddressed and unsolved at the termination of the project. These areas are discussed in this section of the report.

It is important to note that these problem areas do not (in the opinions of the project personnel) impact the feasibility of the project; they do not consist of high technology development requirements, go/no-go decisions, or cost matters which would provide a major basis for the ultimate decision to fly or not to fly. Some of these problem areas have been discussed to a limited extent in other sections of this report, and they are included here to provide topically significant inputs to this particular section.

One hardware-related problem which could have significant impact on the success of a man-made noise experiment is the possibility of RF overload of the receiver input. It is not the effect on output data which is of concern, but rather the possibility of permanent damage to the active components of the preamp stages of the receiver. This problem was not studied in detail during the course of the project. In the event of the use of a parabolic antenna viewing the spacecraft horizon, the problem could be

significant. For example, a radar operating at 5600 MHz with an output eirp of 104 dBW peak (e.g. AN/FPS-16), could produce a power flux density at the satellite location on its horizon of approximately -39 dBW per square meter. With a 1 meter diameter parabolic antenna onboard the satellite, the peak input power level produced would be about -42 dBW. As specified, the satellite receiver's 1 dB compression point is approximately -70 dBW; the input level from such a radar would produce a signal of approximately 28 dB above the overload point of the receiver. Whether this would produce damage to the receiver would depend upon the unspecified tolerance of the receiver's input preamplifiers, which could well "see" the entire spectrum of such a signal. The magnitude of this problem is considered much less (i.e., at 5600 MHz, approximately 30 dB less) if the "full field of view" antennas are in use on the spacecraft, as their effective area would be considerably less than that of the parabolic reflector antenna.

Another problem which has been relatively unconsidered during the course of the project is that relating to the total power requirements for the experiment spacecraft, and the means of supplying those requirements. By way of example, if the receiver requires 30 watts, an onboard recorder 70 watts, the down-link data transmitter 10 watts, a housekeeping and telemetry transmitter 3 watts, the command receiver 5 watts, and the various onboard sensor and control systems 10 watts, all average power levels, then the average power output to the experiment in its "full up" mode of operation could be nominally 130-200 watts (10 to 15 sq. ft. of solar array). The mass of a solar cell array or a spinning body satellite at one AU

to provide that output could weigh on the order of 30-40 kilograms. The size of the satellite, as defined by that output requirement and solar array size would be considerably in excess of anything which could be fitted to a Scout class vehicle, in fact (using data from a common reference source of the late 1960's), a cylindrical array on a spacecraft of nominally 1 meter cross section would require a length of approximately 3 meters.

Another problem relating to the experiment hardware which was not fully addressed relates to the selectivity, or skirt selectivity, of the receiver. Some information on the significance of this aspect of the receiver design is provided in Section 13 in discussing the feasibility hardware for the experiment, but the trade-offs, minimum requirements, etc., have not been established. The importance of this value lies in the desire to inhibit interchannel responses and adjacent channel responses, and the need to completely "reset" the IF sections of the receiver to zero between each successive data sample. Hence, the trade is between the frequency domain, and the time domain. As the skirt selectivity, roll off, or selectance, of each IF channel is increased, the integrity and freedom from adjacent channel response of each measurement is increased; however, the period required to "dump" the energy from the reactive circuits in that channel is increased.

The definition of the spacecraft itself was not addressed and remains an unsolved problem which must be worked for an operational experiment. The type of stabilization for the spacecraft, its size, its mass, etc., all are highly significant interfaces with this experiment.

Yet another area of concern which has been mentioned elsewhere but which was not within the scope of the AAFE project is that relating to the selection of the launch vehicle and the design of the launch phase of the experiment. The launch vehicle selection does not impose a severe area of questionability with respect to the man-made noise experiment.

An area of concern which was considerably closer to those studied under the project reported herein relates to the trade-offs between the various dimensions of data resulting from the experiment. Prior to the implementation of specific experiment missions, resolution dimensions or elemental areas in amplitude, frequency, and geographical space will have to be selected. These selections will influence the data processing and data storage requirements of the experiment, and on the resultant final product or output from the experiment. Such decisions relate to the specific requirements of specified missions, and such missions were not postulated or identified clearly during the course of this project. For this reason, the actual development of qualitative values for the various dimensions must be left to the flight experiment phase.

The statistical significance of data developed during the course of particular flight experiments was not studied in depth during the course of this project, as it will depend on the nature of each experiment mission as well as on the duration of the mission. This area of concern relates primarily to spatial and frequency resolution, and also to the determination of outside limits (maxima and minima) for the various other dimensions of the data in

connection with each experiment mission. For example, if the entire spectrum of the experiment is to be studied, the significance of the statistics developed for each 20 kHz channel must be far less than would be the case if a single 100 MHz band were studied for a similar duration. These determinations regarding the significance and specific mission objectives will bear strongly upon the selection of those objectives.

The "output" machinery setup to provide the final product of the experiment to its ultimate users is an important area of concern, but one which was not required to be addressed during the course of this project. It was assumed that an output user interface would be available to provide experiment data to the widest possible audience; it will be of great importance that such an interface be developed prior to the implementation of such an experiment to provide an ultimately useful product to the community at large.

One additional area not addressed was that relating to the determination of overall project costs: the serious analysis of cost elements and the performance of cost trade-off and value studies remains for the flight experiment developer.

## 15. ALTERNATE APPROACHES

The experiment developed under the AAFE man-made noise experiment project is intended to demonstrate the feasibility of a dedicated experiment in a dedicated spacecraft in a unique orbit to be used for the collection and processing of man-made noise interference data with an output of significant value to a variety of users for a variety of purposes. This project did not represent an optimization study or a total systems analysis of the orbital data collection problem. During its course, numerous alternatives and techniques for the generation of the type data expected from this experiment were considered and were rejected, but it is not felt or believed that this approach represents the only possible or feasible approach; numerous possibilities exist which have not even been explored or conceived at the present time, and among alternative methods and techniques to the development of such data which have been considered, many have been passed up and unexplored during the course of the project because of the constraints on time and overall project objectives. However, it may be worthwhile for a number of the alternative approaches to the development of orbital man-made noise interference data to be mentioned and briefly discussed in this technical report, in order that the scope and limitations of project considerations which involve such alternatives be recorded. Some of the alternative approaches have been discussed elsewhere in the report, but they are re-enumerated in this section for the purpose of their topical significance at this point in the report.

Among the alternative proposals which have been made for man-made noise data collection, the primary ones to receive serious attention entail the use of satellites developed primarily for other purposes than as a platform for instrumentation devoted to the collection of man-made noise data. Among these types of experiments are the one which will have been launched on the ATS-F satellite to collect data in the 5900-6400 MHz band. In the case of this particular experiment, the geostationary orbit will be used for data collection, and a transponder will be used to relay the entire band of concern to the earth station for "spectrum analysis" and data processing. Other experiments of this type have been proposed, and some hardware has been developed for such experiments, necessarily limited in frequency coverage and in temporal or geographic coverage by the primary mission orbit characteristics and the space limitations on dedicated hardware and antennas. The feasibility of such experiments exists and will become considerably greater if they are considered for inclusion on the various space shuttle missions and for manned shuttle laboratories.

The space shuttle may provide a considerable number of flight opportunities for man-made noise data collection experiments not previously identified or currently proposed. In this connection, one such experiment was outlined in a most general form during the course of this project; the Appendix entitled "Advanced Technology Laboratory Man-Made Noise Experiment Description" outlines this particular proposition for a data collection mission

to be orbited in connection with a "sortie lab" effort. Numerous other possibilities can readily be conceived in connection with the space shuttle: among them, perhaps the most promising is the possibility of placing in dedicated orbits or nominally random orbits a number of man-made noise data collection experiments on extremely small dedicated vehicles whose structure and physical configurations would not need to be related to any specific launch vehicle in the current inventory. Of course the possibilities for such opportunities are relatively remote; it is hoped that considerable data concerning the interference environment can be obtained prior to the operational status of the space shuttle. Nonetheless the placement of hardware in orbit by the shuttle, and the conduct of experiments on manned shuttle missions offer exciting possibilities.

The collection of man-made noise data from points at and near the surface of the earth (i.e., less than 100 kilometers altitude) and the use of such data for prediction of interference levels at orbit altitudes has not been fully explored to date. The work which has been done appears to indicate that the limited extent of geographic coverage feasible for such near earth collection platforms, and the difficulties in the integrating data developed from diverse experiments with highly differing types of hardware and data processing severely limits the ultimate value of such data for the development of general coverage and relatively accurate data extrapolated to orbit altitudes. One possibility for near earth data collection which has not, apparently been explored in any depth to date is the placement of a data

collection platform such as the AAFE man-made noise receiver, with appropriate antennas, on balloons for relatively high altitude data collection. The use of high altitude balloons in conjunction with real time tracking and data collection facilities of a mobile sort on the ground might offer an alternative to the expensive aircraft data collection platforms which have been used hitherto for the collection of near earth data.

The use of aircraft as near-earth data collection platforms for man-made noise has been employed to a considerable extent during the past two decades. A number of experiments have provided information concerning the levels and spectra of data in dedicated VHF and UHF in selected urban areas throughout the United States and Europe. A number of these, however, have been carried out at relatively low altitudes wherein the primary output has indicated that such fortuitous interference as ignition noise is the predominant contributor in the bands studied; such data would not have appreciable application for the study of or development of information concerning orbital interference problems. In general, the aircraft provides a versatile platform in terms of transportability for highly specified missions relating to terrestrial data collection, but it is noteworthy that the expense of developing data on an aircraft flown specifically for the collection of such data, to provide general coverage of a land mass of the size of the continental U. S., would be exorbitant. An alternate proposal has been made on occasion: to place data collection hardware for specific bands of interest on commercial aircraft which carry out a wide range and pattern of flights

across the United States. This possibility has not been explored in any depth, and it might be difficult to implement in light of the necessity of interfacing non-carrier owned equipment into the commercial carrier aircraft, but it could provide a source of "broader based" data than otherwise would be available for certain bands.

The development of statistics indicative of man-made noise problems for earth space communications links may be feasible at some time in the near future on the basis of mathematical analysis using existing or to be developed data bases. It is strongly felt, however, that the development of man-made noise data using empirical techniques must precede the reliance on models which have no empirical basis. The development of man-made noise on the basis of a flown experiment could be used to develop a model with adequate accuracy and flexibility to preclude the need for future noise measurement experiments.

The alternate approaches briefly mentioned above in this section are but a few of the many possibilities whose values and relative merits could justify considerable additional study. However, it is felt, on the basis of past experiments and present needs, that the experiment developed under this project will provide a feasible means to generate a much needed data base for use in the improvement and optimization of earth space communications. It is felt that the alternate approaches to this data base development need more study at the present time than the experiment developed under this project.